DEVELOPING A METHOD TO ASSESS THE WORKABILITY OF AN OFFSHORE HEAVY LIFTING OPERATION

M.Sc. Thesis

A.K. Clades

MASTER THESIS REPORT

OFFSHORE ENGINEERING, DELFT UNIVERSITY OF TECHNOLOGY

DEVELOPING A METHOD TO ASSESS THE WORKABILITY OF AN OFFSHORE HEAVY LIFTING OPERATION

ALEXANDROS KONSTANTINOS CLADES, JULY 2018

Preface

This master thesis describes a method to determine the workability of an offshore heavy lift operation. By creating wave realisations based on and statistically equivalent to measured ocean weather data, a quick assessment of the risk of failure can be achieved.

The graduation committee members:

Prof. dr. ir. A.P. van ‘t Veer	Delft University of Technology
ir. J. den Haan	Delft University of Technology
…	

To my loving parents, Labros and Hella, without whose support and neverending patience this long journey would not have been possible.

I’m also greatly indebted to Joost den Haan, whose relentless enthusiasm and infectious curiosity was instrumental in making this thesis a reality. A true teacher in every sense of the word.

Lastly, I’d like to offer the eternal gratitude of a forgetful man to my dear friends, Sándor Hötte and René Oudeman, who offered help when I didn’t ask for it and did so assiduously, and to Adriaan van Tets and Dingeman Kooyman who supported me in the last few months.

ΙΘΑΚΗ

Σὰ βγεῖς στὸν πηγαιμὸ γιὰ τὴν Ἰθάκη,
νὰ εὔχεσαι νἆναι μακρὺς ὁ δρόμος,
γεμάτος περιπέτειες, γεμάτος γνώσεις.
Τοὺς Λαιστρυγόνας καὶ τοὺς Κύκλωπας,
τὸν θυμωμένο Ποσειδῶνα μὴ φοβᾶσαι,
τέτοια στὸν δρόμο σου ποτέ σου δὲν θὰ βρεῖς,
ἂν μέν᾿ ἡ σκέψις σου ὑψηλή, ἂν ἐκλεκτὴ
συγκίνησις τὸ πνεῦμα καὶ τὸ σῶμα σου ἀγγίζει.
Τοὺς Λαιστρυγόνας καὶ τοὺς Κύκλωπας,
τὸν ἄγριο Ποσειδῶνα δὲν θὰ συναντήσεις,
ἂν δὲν τοὺς κουβανεῖς μὲς στὴν ψυχή σου,
ἂν ἡ ψυχή σου δὲν τοὺς στήνει ἐμπρός σου.

Νὰ εὔχεσαι νἆναι μακρὺς ὁ δρόμος.
Πολλὰ τὰ καλοκαιρινὰ πρωϊὰ νὰ εἶναι
ποῦ μὲ τὶ εὐχαρίστηση, μὲ τὶ χαρὰ
θὰ μπαίνεις σὲ λιμένας πρωτοειδωμένους·
νὰ σταματήσεις σ᾿ ἐμπορεῖα Φοινικικά,
καὶ τὲς καλὲς πραγμάτειες ν᾿ ἀποκτήσεις,
σεντέφια καὶ κοράλλια, κεχριμπάρια κ᾿ ἔβενους,
καὶ ἡδονικὰ μυρωδικὰ κάθε λογῆς,
ὅσο μπορεῖς πιὸ ἄφθονα ἡδονικὰ μυρωδικά·
σὲ πόλεις Αἰγυπτιακὲς πολλὲς νὰ πᾷς,
νὰ μάθεις καὶ νὰ μάθεις ἀπ᾿ τοὺς σπουδασμένους.

Πάντα στὸν νοῦ σου νἄχεις τὴν ᾿Ιθάκη.
Τὸ φθάσιμον ἐκεῖ εἶν᾿ ὁ προορισμός σου.
᾿Αλλὰ μὴ βιάζεις τὸ ταξεῖδι διόλου.
Καλλίτερα χρόνια πολλὰ νὰ διαρκέσει·
καὶ γέρος πιὰ ν᾿ ἀράξεις στὸ νησί,
πλούσιος μὲ ὅσα κέρδισες στὸν δρόμο,
μὴ προσδοκῶντας πλούτη νὰ σὲ δώσει ἡ ᾿Ιθάκη.

Ἡ ᾿Ιθάκη σ᾿ ἔδωσε τ᾿ ὡραῖο ταξεῖδι.
Χωρὶς αὐτὴν δὲν θἄβγαινες στὸν δρόμο.
Ἄλλα δὲν ἔχει νὰ σὲ δώσει πιά.

Κι ἂν πτωχικὴ τὴν βρεῖς, ἡ ᾿Ιθάκη δὲν σὲ γέλασε.
Ἔτσι σοφὸς ποῦ ἔγινες, μὲ τόση πεῖρα,
ἤδη θὰ τὸ κατάλαβες ἡ ᾿Ιθάκες τὶ σημαίνουν.

Κ.Π. ΚΑΒΑΦΗΣ (1863 – 1933)

Table of Contents

Chapter 1

Introduction

1.1 The Offshore Market

The offshore market has gone through rapid changes over the past several years. Initial enthusiasm caused by advances in methods to extract hydrocarbons from ever deeper waters, as well as arctic regions soon turned into a near total stop in new investments following the 2008 financial crisis which caused a huge drop in demand for energy.

Dutch companies have a particularly long history in shipping in general and in servicing the offshore market in particular, not in the least because of a flourishing sector that has grown around Shell over the years.

Several of these have tried to stay ahead of the curve recently by developing more versatile vessels, either capable of higher cruising speeds, the ability to lift heavier loads with ever bigger cranes. Others have focused on the promising arctic drilling and building vessels that can sail through thick layers of ice, enabling them to operate for longer working seasons or enabling them to cut short shipping routes in the arctic region. Even regular transport vessels are now increasingly travelling to Asia from Europe by sailing North of Russia, greatly cutting the distance and the costs to ship goods.

1.2 The Dutch players

Several Dutch companies are competing for market share in this segment. HMC is a large player in the offshore sector and its Aegir is treated in this thesis as it is the offshore construction vessel that does the lifting in the operation considered in this thesis.

Jumbo has a longstanding record in the industry as well and its Fairplayer vessel is a versatile vessel with two cranes capable of lifting 900 mt loads over a lifting radius of 30 m.

Figure 1.1 Jumbo’s Fair player

Another class of vessels owned by Jumbo are fitted with two 1500 mt cranes leading to a combined lifting capacity of 3000 mt. Their design is older however and they lack a flush deck that is in higher demand for offshore operations.

1.3 Offshore Supply Vessels

BigLift is another important player in the market own and, together with RollDock launched a class of vessels named the MC-Class, a Heavy Lift Offshore Supply Vessel (HLOSV). It is well- suited to transport Heerema reels to Heerema’s Aegir due to its flush desk, high speed and ice class specifications. As both the Aegir and the MC-Class are state of the art modern and versatile vessels, the operation considered uses these two vessels as a basis for the thesis. More information on the MC Class can be found in Chapter 3.

Chapter 2

Approach

2.1 Problem Definition

The goal of this research is to gain extensive insight into the operability of a typical heavy lift vessel and develop a method to quickly assess the risk involved in a critical operation. While the MC-Class was designed to perform numerous different tasks, the research will focus on one specific, rather complex operation because it is more fruitful and better suited to the scope of a thesis to consider one operation in detail than it is to look at a wide range of operations superficially.

The operation at hand consists of offloading a heavy load at sea. A long-time customer, Heerema, operates a new pipe laying vessel, the Aegir. A contract that is under consideration consists of supplying 3000mt reels to the Aegir, which can lift them from the deck of an MC-Class. The offshore supply of the reels enables Heerema to continue the pipe laying process without operating an expensive vessel to pick up the reels from a faraway port.

Out of many possible tasks, this task was chosen because it is demanding: The load is very heavy and it needs to be transferred at sea. This research examines this offloading operation in detail and aims to define for which sea states the operation can be conducted safely. The difficulty of the operation lies in the fact that the lifting of a very heavy load off a vessel can cause a significant change in stability of both the vessels. This can lead to the loss of the load or result in the load colliding with the MC-Class deck. This would almost certainly result in a lot of damage to both the load and the vessel and must be avoided.

A model should therefore be developed which can accurately predict the dynamics of the lift using hindsight ocean weather data. Ideally, it should be capable of assessing not only the chances of a collision occurring between the load and the deck during the lift, but also the speed with which this would occur, as this is a critical factor in the overall risk assessment.

More precisely, for which conditions do high velocity impacts occur between load and deck, and to which extent do different factors contribute to this risk.

To gain better insight into this risk, special attention will be paid to the stochastics surrounding the chances of impact and the velocity at which these occur. A better understanding of these statistics can point to better and more efficient ways of mitigating the risks involved during this type of lift.

2.2 Research objectives

The primary research objective has been defined as follows:

> *"Develop a method to quickly assess the workability of a heavy lift operation at sea."*

More specifically, answers should be found to the following questions:

1. *How can the relative vertical motion of the cargo with respect to the MC-Class deck during the lifting operation best be modelled?*

   When lifting a heavy load off the deck, the system stability could suddenly change substantially. These sudden changes in the stability can affect the hydrodynamics, which, in turn, can lead to dangerous situations such as the loss of cargo or damage to the vessel.

2. *How do different environmental conditions influence the workability of the operation?*

3. *Which factors and criteria have the largest impact on the workability?*

Particular attention will be paid to the stochastic details surrounding the operation. More specifically the surface elevation, which follows a Gaussian distribution, the most probable extremes in wave height, which fit a Rayleigh distribution. The impact velocities also quite neatly fit a probability distribution function, to be discovered by the reader in Chapter 6.

2.3 Research Method

In order to answer the above questions, both vessels and the operation will first be described in detail in **Chapter 3**. The entire lifting operation is subdivided into five shorter, consecutive steps. For each of these steps, relevant criteria will be formulated from which the most important ones, the ones most critical for the operation, will serve as a basis for determining the overall workability of the operation. Special attention is given to the moment that is most limiting in terms of workability, namely right after the load's "take-off" from the deck. It is imperative that no collision occurs between the load and the deck of the MC-Class that can damage both deck and load.

In **Chapter 4,** the theory that underpins the workability analysis is considered. Metocean data and wave scatter diagrams are explained, as well as the derivation of the relative response of both vessels in various sea states. Two different methods are used to calculate the workability. These are also explained in this chapter. The first is a classical frequency domain (FD) analysis using JONSWAP spectra. This will be used to determine roughly which months or seasons have weather conditions allowing for the operation to be conducted safely.

A second, more refined method called "FD+" is able to easily generate many realistic wave records that can be used to determine the chances of collision between the reel and the deck occurring, as well as the impact velocity at which this occurs. This is done by using a real, measured wave record, converting this into a wave spectrum and then adding random phases to each wave in the wave spectrum to create a large number of new, artificial but statistically realistic wave records. By modelling the gap between the load and the deck, not only the chances of collision but also the speed at which this occurs can then be determined for different sea states with a high degree of certainty.

Next, **Chapter 5** will detail the equations of motion that govern the system and explain how the system is modelled in Ansys AQWA and MATLAB.

Chapter 6 will present the results of the analysis and give an overview of the workability for each step of the operation. The influence of the various criteria and how they affect workability will also be treated in this chapter.

This is done in the ("regular") frequency domain for the first step (and the fourth step, which is very similar). For the steps that consist of the hook-on and actual lifting of the reel, a more refined method is used, the so-called "Frequency Domain +" (FD+). The motion behaviour will be examined for different environmental circumstances, and the influence of various factors such as the relative position of the vessels and the influence of roll damping will be examined.

Furthermore, a stochastic analysis of the frequency of impacts as well as their velocities will be examined at the end of this chapter.

Chapter 7 will give an overview of the conclusions that can be drawn from this research, as well as some direction for possible future research into the operability of the vessel. A critical look at the limitations of this method can also be expected.

In **Chapter 8**, the recommendations are presented and **Chapter 9** lists the bibliography that has been consulted during this research.

Chapter 3

Operation and Criteria

3.1 Offshore Supply Vessel

The Offshore Supply Vessel is an offshore supply vessel designed for the transportation of very large and heavy loads. It was conceived by BigLift which until then only served the port-to-port market when the shipping sector took a hit in the aftermath of the 2008 financial crisis. Given that the oil and gas industry continued to perform well and given the many years of experience in the heavy lifting sector, a joint venture with RollDock was established called BigRoll which ordered the MC-Class vessels to serve the Offshore market.

The MC-Class has an overall length of 171 metres and a width of 42 metres. It has an open deck space of 5400 m2 entirely free of manholes or other objects. Its displacement is 23000 Mt and it has ice class certification meaning it is suitable for operations in the arctic.

It has Class 2 Dynamic Positioning and can discharge ballast water at a rate of 12000 m3/hr.

Due to the fact that the deck is open and entirely flat, it is a flexible vessel and it is very well suited for the job considered in this thesis. The load, two Heerema reels, are placed on deck as shown in the figure below.

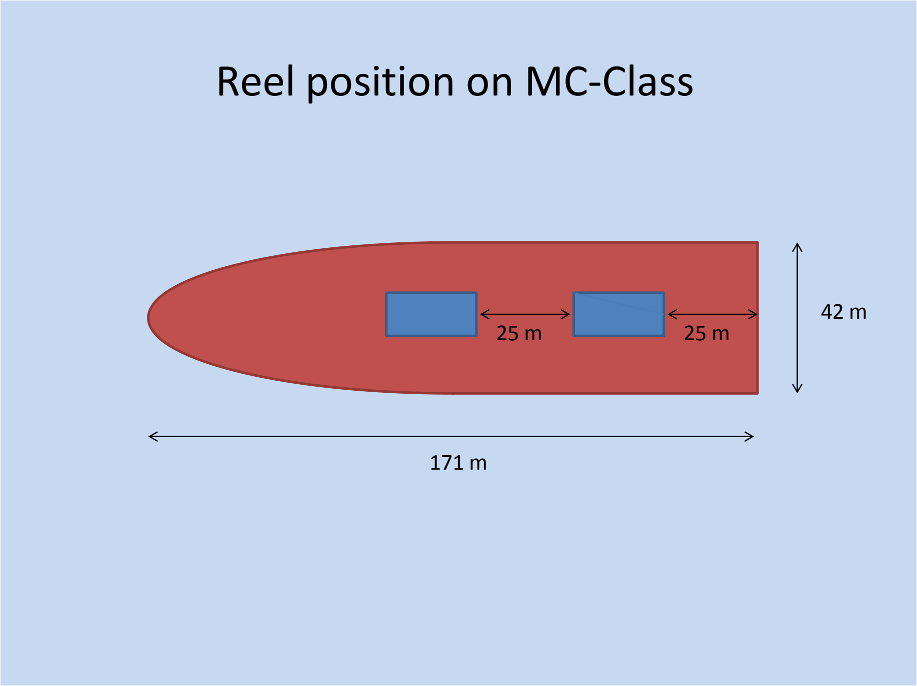


Figure 3.1: Position of Reels on MC-Class deck

The reels have a length of 25 metres, height of 25 metres and are approximately 12 metres in width. They are transported pre-rigged.

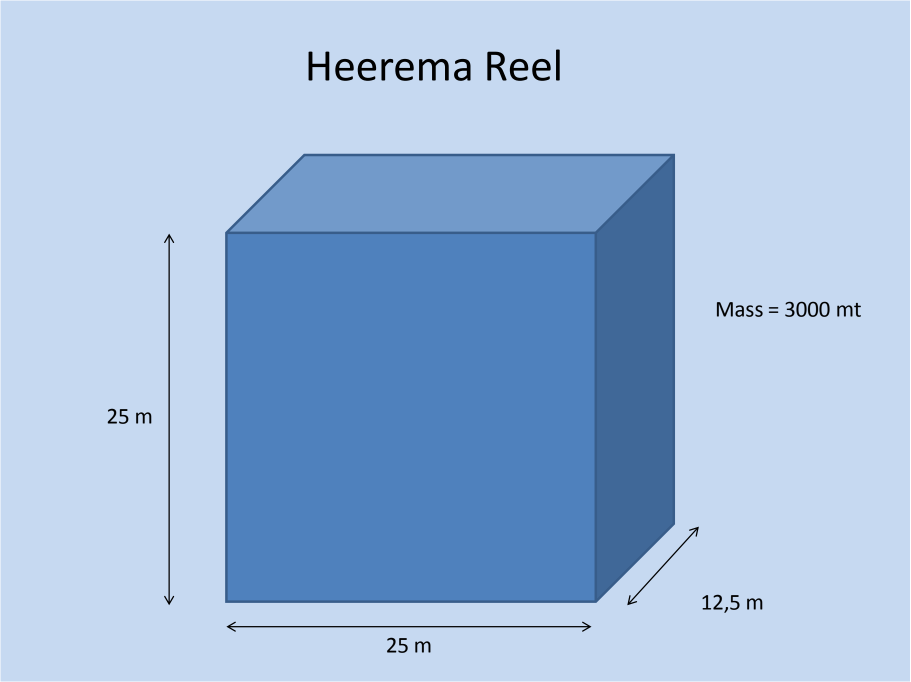


Figure 3.2: Outer dimensions of Heerema reel

3.2 Aegir

The Aegir is Heerema’s largest deepwater construction vessel (DCV). With an overall length of 210 m, a width of 46 m and an operating draft of around 10 m, it was added to Heerema’s fleet in 2013 and is capable of multiple tasks in the offshore industry. It can lay pipes in ultra-deep water and has a lifting capacity enabling it to install fixed platforms in relatively shallow water.

Figure 3.3: Heerema's Aegir with reel

Its heavy lift crane has a boom length of 125 m and has the capacity to lift 4000 mt over a radius of 17 to 40 m.

The pipelay tower can be used for both J-Lay and reeling and can lower pipes to a water depth of up to 3500 m.

Figure 3.4: Heerema's Aegir

It has a Class 3 DP system and a total power plant output of 48 MW consisting of six diesel engine generators of 8 MW each.

As it is costly to operate, it is more cost efficient for other vessels to transport the reels to the Aegir hen it is constructing a pipeline. The reels come pre-rigged so they can easily be lifted by the Aegir once they have arrived. On board the Aegir, there is room not just for the reel that is being used, but also for an extra full one, as well

3.3 Description of the operation

The operation that will be researched consists of a heavy lift at sea of two large Heerema reels weighing 3000mt each. They are transported by the MC-Class to the Heerema's Aegir, an offshore installation vessel, to be used in a pipe laying operation. The trip from the port to the location where the heavy lift operation takes place is beyond the scope of this thesis.

The entire lifting operation consists of six consecutive steps. These six steps are:

1. Arrival and positioning of MC-Class next to Aegir
2. First hook-on
3. Lifting of (first) reel
4. Repositioning
5. Second hook-on
6. Lifting of second reel

These steps have different durations and different safety standards and criteria are associated with each step. These affect the decision on whether the go-ahead can be given to begin with the next step at the outset of each step. *"To begin, or not to begin, that is the question!"*

A detailed description of abovementioned steps, as well as the relevant criteria is given in the next section of this thesis.

3.3.1 Arrival and positioning

When the MC-Class reaches the Aegir is operating, it needs to position itself next to the Aegir. A decision has to be made by the captain based on safety standards and operational criteria whether the environmental conditions allow for the two vessels to be in relatively close range. The positioning is done using its Dynamic Positioning system which also controls the vessel's position during the lifting operation. The MC positions itself on the Aegir's starboard side as this is the side where the Aegir's crane is located.

In order for the reel to be as close to the crane as possible the MC-Class will position itself parallel to the Aegir at a distance of 5 meters. The relative position in x-direction, 42,5 metres, is chosen such that the reel's hook is as closely aligned to the crane as possible. Heerema's Aegir uses Yokohama's (one every 20 m) to prevent a collision of the two vessels.

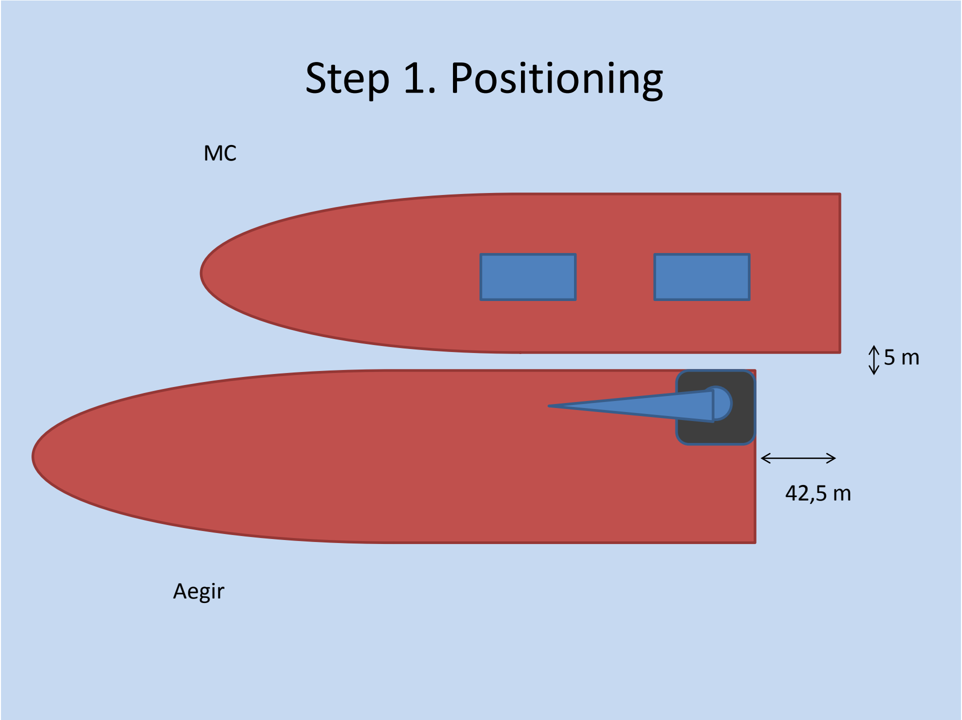


Figure 3.6: Relative position of vessels

If we define this step as beginning when the MC-Class has come within a distance of 50 metres from the Aegir, and the end of this step to be when the MC-Class has positioned itself in the desired location, this step can take up to one hour.

The critical part of this step of the operation is that the vessels should not be in danger of collision when the MC-Class positions itself next to the Aegir. This depends on the DP systems of both vessels ensuring that a safe and constant distance between the ships is maintained. As the Aegir has DP Class 3, and the MC is rated Class 2, the criteria of the MC Class will be used as they are the weakest link. These criteria are related to a wide range of conditions, such as wave heights, but also currents and wind conditions. As only the influence of waves is assessed here, a maximum significant wave height of 2,5 m will be used as the relevant criterium. This means that the decision to position the MC next to the Aegir is taken when the significant wave height is not expected to exceed 2,5 m for at least one hour.

3.3.2 First hook-on

Once the MC-Class is in the right relative position with respect to the Aegir, the Aegir's crane has to perform the hook-on to the reel. The reel's eye is located approximately 5 m above the centre of the reel, so 30 m above the deck of the MC. Also, the Aegir's tugger winch is hooked onto the reel near the lower end of the reel. It serves to provide constant tension throughout the lift to prevent the reel from swaying in the air and causing instability.

In order to perform this step successfully, the relative motions of the crane's hook and the reel's eye cannot exceed 1 m/s in any direction, to prevent the hook and the eye from severely damaging each other. The 12 mt hook's swaying due to wind is negligible and is not taken into account when, in the next chapter, the workability is calculated.

Due to the fact that men are on deck to assist with guiding the hook-on, criteria concerning the safety of the workers also apply here and therefore the vertical accelerations cannot exceed 0.15 g, the lateral accelerations cannot exceed 0.07 g, and the roll angle cannot exceed 4.0 deg at the deck level. This step can take up to two hours. These are the two criteria that apply to this step in the operation. The go-ahead of this step is given by the crane operator of the Aegir.

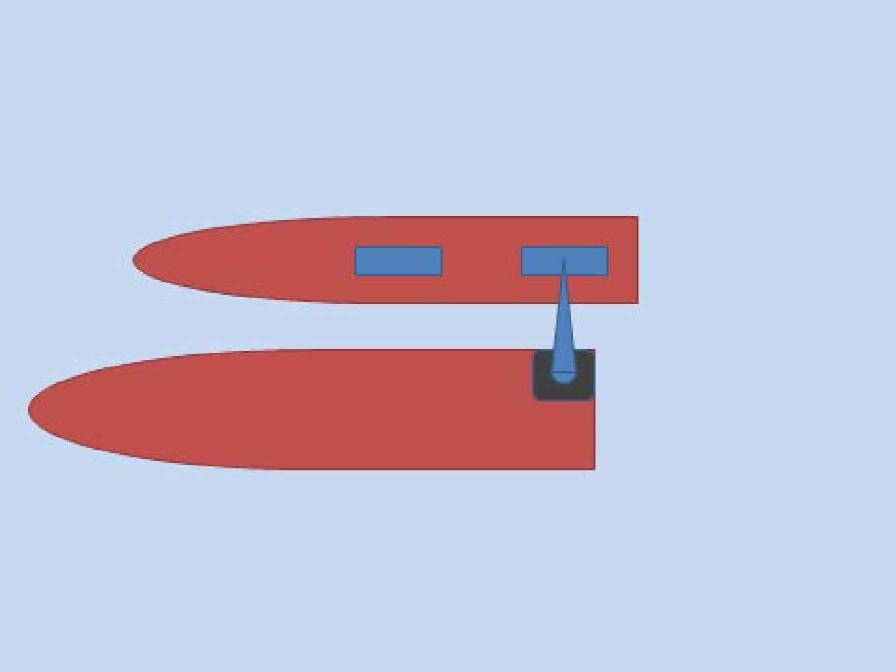


Figure 3.7: Crane above reel

3.3.3 Lifting of first reel

After the hook-on has been performed successfully, the actual lift can be performed. The whole lifting operation can last 4 to 5 hours, but the critical part of the lift lasts only a few minutes. In fact, this is when the most crucial decision of the entire operation needs to be made: The decision to proceed with the actual lifting of the reel, a so-called point of no return. This is done by assessing the probability of a wave occurring that will result in the collision of the reel and the deck. Obviously, such an event must be extremely unlikely for the go-ahead to be given for the heavy lift. Due to the confidentiality of a number of technical details surrounding the capabilities of the crane, some educated assumptions need to be made.

First, the exact hoisting speed of the crane is known only to be less than 1 m/s. Comparisons with similar cranes and payloads, as well as analysis of video footage of other heavy lifting operations suggests a hoisting speed of around 0,1 to 0,2 m/s.

The slack length of the cable is assumed to be 2 m. This means that with a conservative estimate of the hoisting speed at a constant 0,1 m/s, it would take 50 seconds for the reel to be lifted 3 m above the deck from the moment the go-ahead is given.

Pictured below is a lift of the same reel from a barge instead of an MC-Class vessel courtesy of Heerema. Other than that, the lifting operation is the same.

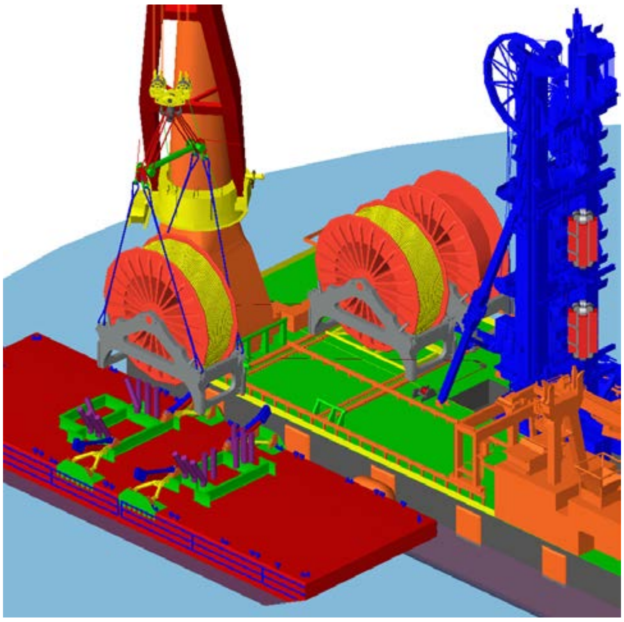


Figure 3.8: 3D rendering of lift (from a barge)

The criteria for this step are two-fold. The criteria of the previous steps are valid here as well, and a probability of collision of at most 0,001 will be regarded as safe enough. Collisions between reel and deck with a velocity less than 0,2 m/s will not be regarded as unsafe in this regard.

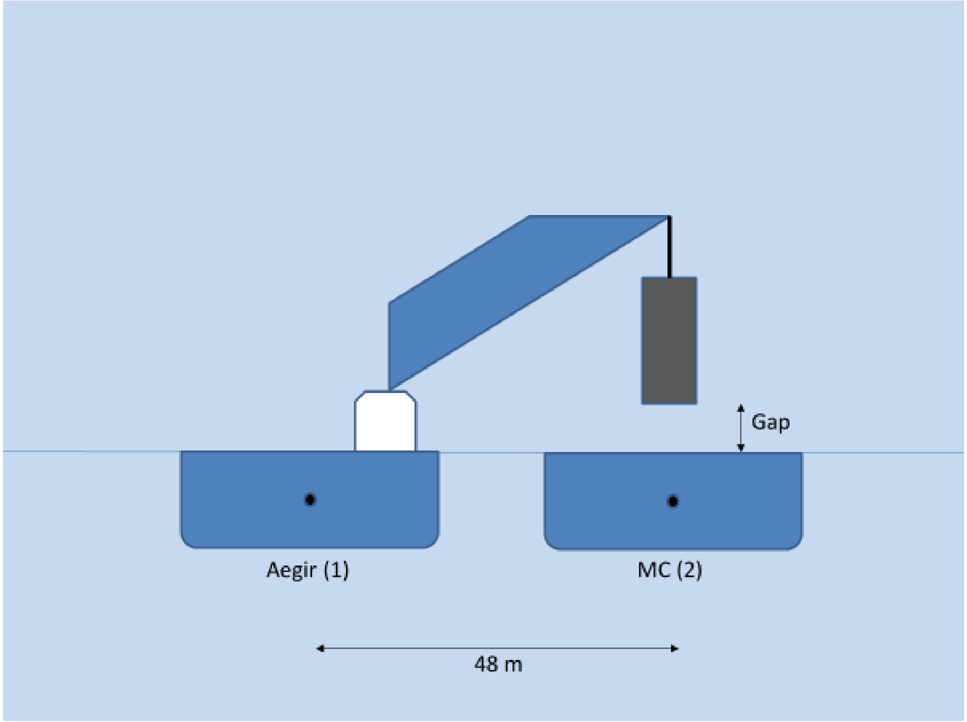


Figure 3.9: Rear-end view of the lift

3.3.4 Repositioning

After the first reel has been lifted successfully and placed on the Aegir, the MC-Class needs to reposition itself with respect to the Aegir before the second reel can be lifted. The second reel is located 50 meters in front of the first reel, so the MC-Class needs to move astern 50 meters. This is done using the DP system so the DP criteria apply. This step lasts 1 hour.

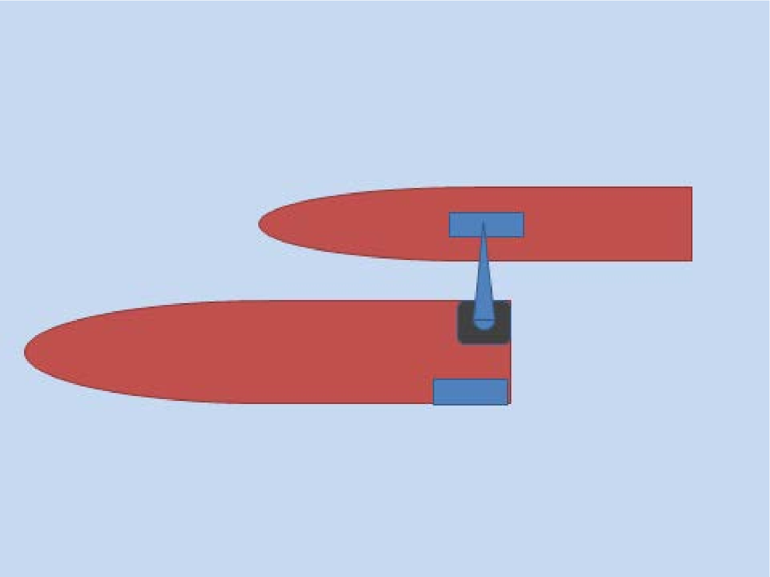


Figure 3.10: Positioning for the second lift

3.3.5 Second hook-on

This step is almost exactly the same as step 2, so details can be found above.

3.3.6 Lifting of second reel

The hook-on of the second reel is similar to the first reel. The lifting of the second reel, however, is a repetition of the operation described above with a few differences. One difference is the relative position of the vessels. The other is the change in stability of both vessels due to the transfer of the first reel from the MC-Class to the Aegir. This difference in mass affects the motion behaviour of both vessels and is taken into account when considering the second lift.

The same criteria apply for the hook-on and lifting of the second reel as for the first one. This is also evident in the table below.

3.4 Criteria

The criteria mentioned in the previous section that detail each step of the operation are based on several sources. An interview has been conducted with someone who works on the Aegir, but also industry regulations or standards, such as the one in the table below. Due to discretion on the part of Heerema employees, the criteria derived from industry standards will be used unless otherwise stated.

Criteria for Accelerations and Roll (NORDFORSK, 1987)

Description	RMS vertical acceleration	RMS lateral acceleration	RMS roll
Light manual work	0.20 g	0.10 g	6.0 deg
Heavy manual work	0.15 g	0.07 g	4.0 deg
Intellectual work	0.10 g	0.05 g	3.0 deg
Transit passengers	0.05 g	0.04 g	2.5 deg
Cruise liner	0.02 g	0.03 g	2.0 deg

Table 3.1: NordForsk Criteria for accelerations and roll

Schematically, the criteria relating to each step of the operation, as well as the exact location to which they apply, looks as follows:

Criteria	Type	Location	Type	Value	
1. Arrival					
1a	Absolute	MC	Significant wave height	3	m
2. First Hook-on					
2a	Absolute	MC	Significant wave height	2,5	m
2b	Absolute	Deck	Acceleration (X)	0,07	g
2c	Absolute	Deck	Acceleration (Y)	0,07	g
2d	Absolute	Deck	Acceleration (Z)	0,15	g
2e	Absolute	Deck	Rotation (RX)	4	deg
3. First Lift					
3a	Absolute	MC	Significant wave height	2,5	m
3b	Absolute	Deck	Acceleration (X)	0,07	g
3c	Absolute	Deck	Acceleration (Y)	0,07	g
3d	Absolute	Deck	Acceleration (Z)	0,15	g
3e	Absolute	Deck	Rotation (RX)	4	deg
3f	Relative	Reel vs Deck	Impact velocity (Z)	0,2	m/s
4. Repositioning					
1a	Absolute	MC	Significant wave height	3	m
5. Second Hook-on					
2a	Absolute	MC	Significant wave height	2,5	m
2b	Absolute	Deck	Acceleration (X)	0,07	g
2c	Absolute	Deck	Acceleration (Y)	0,07	g
2d	Absolute	Deck	Acceleration (Z)	0,15	g
2e	Absolute	Deck	Rotation (RX)	4	deg
6. Second Lift					
3a	Absolute	MC	Significant wave height	2,5	m
3b	Absolute	Deck	Acceleration (X)	0,07	g
3c	Absolute	Deck	Acceleration (Y)	0,07	g
3d	Absolute	Deck	Acceleration (Z)	0,15	g
3e	Absolute	Deck	Rotation (RX)	4	deg
3f	Relative	Reel vs Deck	Impact velocity (Z)	0,2	m/s

Table 3.2: Criteria for each step of the operation

Due to the fact that many of these criteria overlap, a more compact way to visualize them is shown below.

STEP 1	STEP 2	STEP 3	STEP 4	STEP 5	STEP 6
		Criteria 3			**Criteria 3**
		3f			3f
	Criteria 2			**Criteria 2**	
	2a	2a		2a	2a
	2b	2b		2b	2b
	2c	2c		2c	2c
	2d	2d		2d	2d
	2e	2e		2e	2e
Criteria 1					
1a	1a	1a	1a	1a	1a

Table 3.3: Criteria "build-up"

Chapter 4

Theory

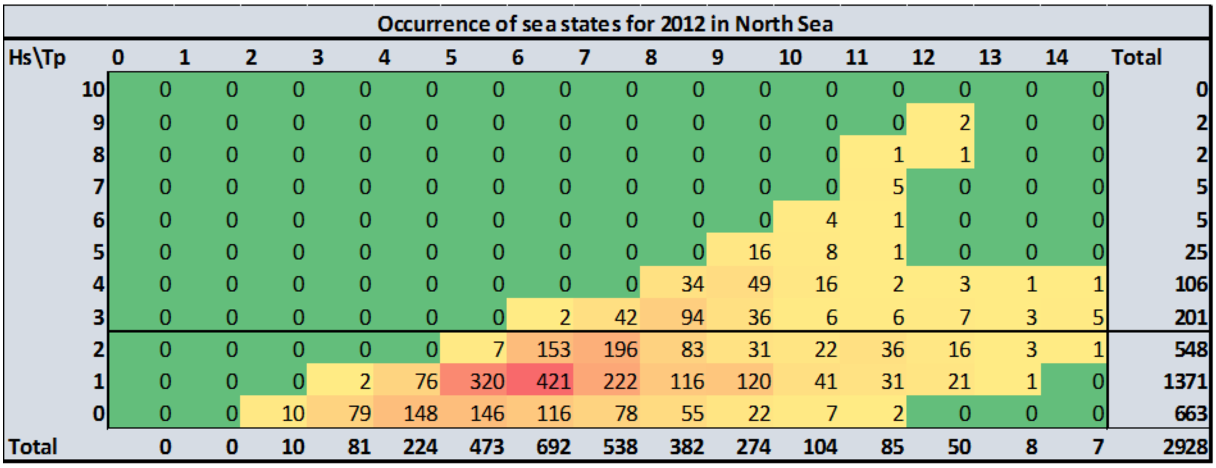
In order to arrive at the workability of an operation at a specific location, a number of calculation steps are taken. The theory behind those calculation steps is treated first in this chapter. Next, a second method to calculate the workability, the so-called Frequency Domain Plus is given at the end of the first part of this chapter.

4.1 Wave Scatter Diagram

First, statistical information is needed about the type of waves that occur at the location we’re interested in. This typically comes in the form of a wave scatter diagram. This diagram is a statistical representation of the occurrence of different sea states at a given location. A sea state tells us two things about waves;

1) Wave height (Hs)
2) Period (Tz)

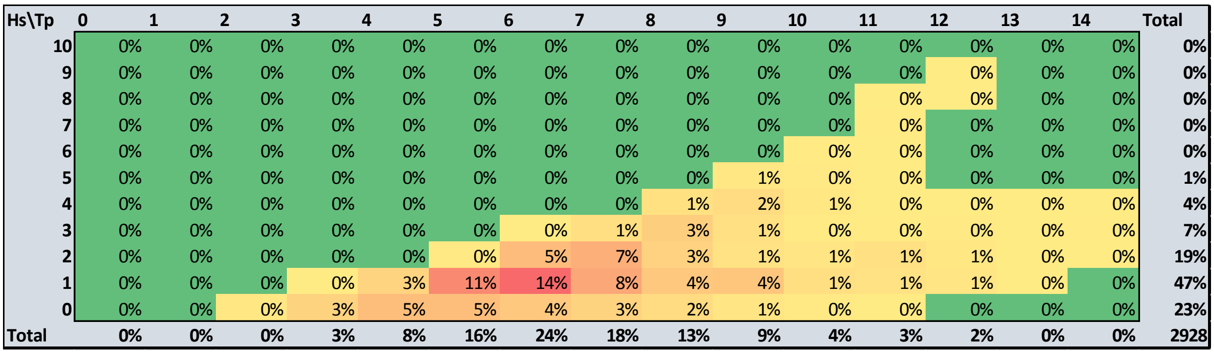
For the chosen location in the North Sea, this is what the wave scatter diagram looks like:



Occurrence of sea states for 2012 in North Sea																
Hs\Tp	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Total**
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
9	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	**2**
8	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	**2**
7	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	**5**
6	0	0	0	0	0	0	0	0	0	0	4	1	0	0	0	**5**
5	0	0	0	0	0	0	0	0	0	16	8	1	0	0	0	**25**
4	0	0	0	0	0	0	0	0	34	49	16	2	3	1	1	**106**
3	0	0	0	0	0	0	2	42	94	36	6	6	7	3	5	**201**
2	0	0	0	0	0	7	153	196	83	31	22	36	16	3	1	**548**
1	0	0	0	2	76	320	421	222	116	120	41	31	21	1	0	**1371**
0	0	0	10	79	148	146	116	78	55	22	7	2	0	0	0	**663**
Total	**0**	**0**	**10**	**81**	**224**	**473**	**692**	**538**	**382**	**274**	**104**	**85**	**50**	**8**	**7**	**2928**

Figure 4.1: Wave scatter diagram

As the total number of waves in the diagram adds up to 1000, the occurrences can be read as percentages. For instance, the sea state that occurs most often in this particular section of the North Sea, has a significant wave height between 1,5 m and 2 m, and a mean wave period between 7 and 8 seconds. Of 1000 waves, 4.4 waves fit this description.



Hs\Tp	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
10	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**
9	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**
8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**
7	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**
6	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**
5	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	**1%**
4	0%	0%	0%	0%	0%	0%	0%	0%	1%	2%	1%	0%	0%	0%	0%	**4%**
3	0%	0%	0%	0%	0%	0%	0%	1%	3%	1%	0%	0%	0%	0%	0%	**7%**
2	0%	0%	0%	0%	0%	0%	5%	7%	3%	1%	1%	1%	1%	0%	0%	**19%**
1	0%	0%	0%	0%	3%	11%	14%	8%	4%	4%	1%	1%	1%	0%	0%	**47%**
0	0%	0%	0%	3%	5%	5%	4%	3%	2%	1%	0%	0%	0%	0%	0%	**23%**
Total	**0%**	**0%**	**0%**	**3%**	**8%**	**16%**	**24%**	**18%**	**13%**	**9%**	**4%**	**3%**	**2%**	**0%**	**0%**	**2928**

Figure 4.2: WSD in percentages.

4.2 Wave Spectra

Next, a wave spectrum is chosen which accurately describes the distribution of wave energy over the frequency spectrum at a specific location. Different wave spectra exist, where a more developed sea state with swell waves has a relatively narrow spectrum, as most energy is located at or very near the peak period Tp. When waves are less regular, the wave energy is spread over a wider frequency band, resulting in a spectrum that is wider and less "peaked".

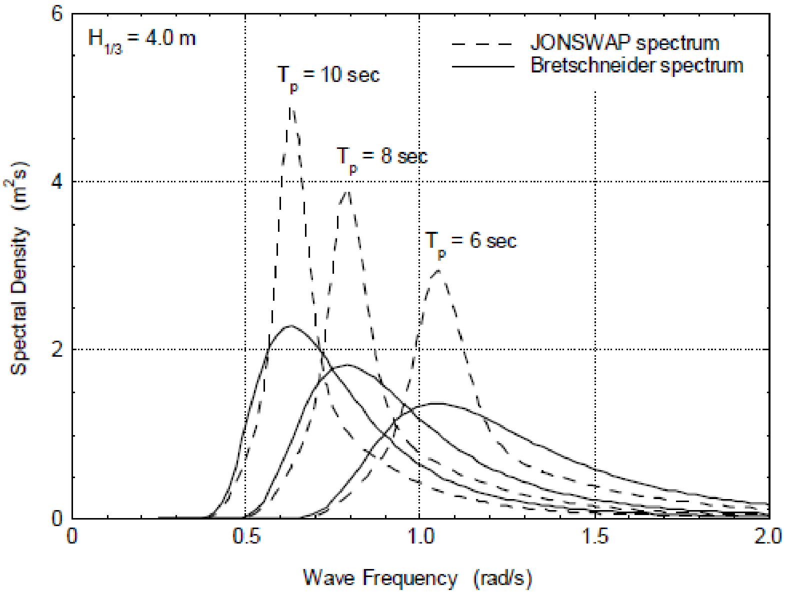


Figure 4.3: JONSWAP vs Bretschneider wave spectrum

The two most commonly used wave spectra are the JONSWAP spectrum and the Bretschneider spectrum, both pictured above. The former is narrower and describes the more developed sea states best. It clearly shows the narrower frequency band in which the energy is contained in the JONSWAP spectrum. As swell is dominant in the location of interest, the JONSWAP spectrum will be used for this thesis. The details of this spectrum are given below.

$$S_{xx}(\omega) = \frac{320 \cdot H_s^2}{T_p^4} \cdot \omega^{-5} \cdot exp\left\{\frac{-1950}{T_p^4} \cdot \omega^{-4}\right\} \cdot \gamma^A$$

Where,

$$\gamma = Peakedness\ factor\ (3.3)$$

$$A = exp\left\{-\left(\frac{\left[\frac{\omega}{\omega_p} - 1\right]}{\sigma\sqrt{2}}\right)^2\right\}$$

$$\omega_p = \frac{2\pi}{T_p}\ (Peak\ frequency)$$

$$\sigma = 0.07\ for\ \omega < \omega_p$$

$$\sigma = 0.09\ for\ \omega > \omega_p$$

And,

$$S_{xx} = Wave\ spectrum$$

$$H_s = Peak\ wave\ height$$

$$T_p = Peak\ period$$

$$\omega = Frequency$$

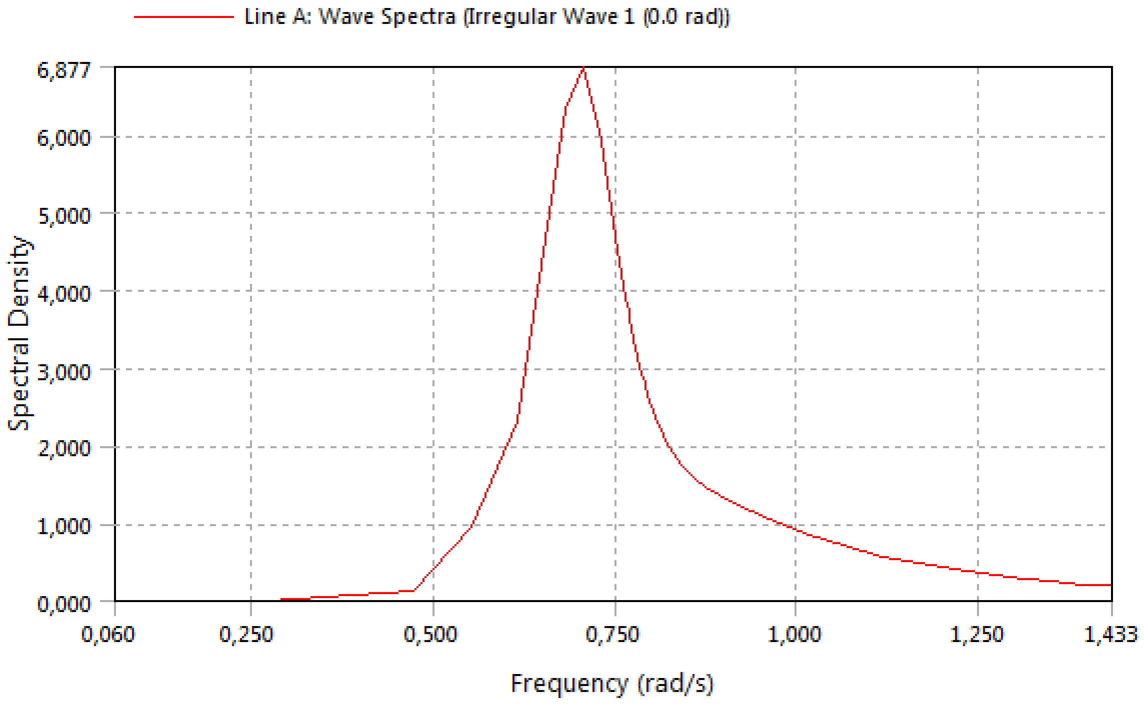


Figure 4.4: Spectral density

A problem arises when using the wave scatter diagram data to compute a wave spectrum. This is due to the fact that the period as defined in the wave scatter diagram is the period between two zero-crossings (the moment the surface elevation passes its mean). The period used as input for the wave spectrum, however, is the peak period. These can be converted using the following equation:

$$T_p = 1{,}287 \cdot T_z$$

Where,

$$T_p = Peak\ period$$

$$T_z = Zero - crossing\ period$$

4.3 Response Amplitude Operators (RAOs) and Response Spectrum

RAOs or Response Amplitude Operators are transfer functions which describe the relation between incoming regular waves and the resulting response of a vessel for a specific motion direction:

$$S_{yy}(\omega) = S_{xx}(\omega) \cdot |H(\omega)|^2$$

Where,

$$S_{yy}(\omega) = Response\ Spectrum$$

$$S_{xx}(\omega) = Incoming\ Wave\ Spectrum$$

$$H(\omega) = Transfer\ Function\ (RAO)$$

This transfer function serves to calculate the so-called *Response Spectrum* of a vessel and depends on the underwater shape and (in case the vessel is moving) the speed of the vessel, as wel as on the frequency and direction of the incoming waves. The *Response Spectrum* describes the motions of a vessel for a range of frequencies.

Below are two examples of a wave spectrum(above), an RAO (middle) and the resulting Response Spectrum (below).

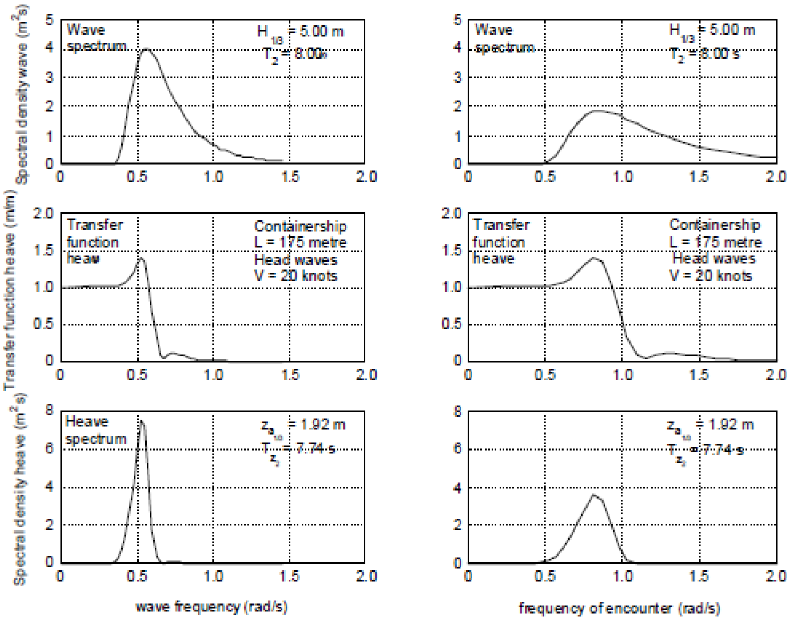


Figure 4.5: Wave spectra (top), transfer functions (middle), response spectra (bottom)

To a large extent, the workability of the operation depends on relative motions of the vessels. A lot of attention will be paid to the relative distance between the load and the deck further on in this thesis. This relative distance or “gap” follows from the response of both vessels and has its own response. The derivation of this gap response can be found in chapter 4.2. below.

4.4 Most Probable Maximum

Next step in calculating the workability of an operation is calculating the Most Probable Maximum (or Most Probable Extreme as it’s also known). The response spectrum describes the response of a vessel to a certain wave but does not contain any information on the likelihood of a wave and related response above a certain value occurring. As this is crucial for determining the workability of an operation, a statistical element needs to be accounted for. This is done using the so-called *most probable maximum*, or MPM. This is a measure of the most likely maximum response that will occur during a specified time window. It is calculated as follows:

$$MPM = MN + \sigma \cdot \sqrt{2 \cdot \ln\left(\frac{N}{\alpha}\right)}$$

$$H_{max} = 1{,}86 \cdot MPM$$

$$MPM = Most\ Probable\ Maximum$$

$$H_{max} = Maximum\ Expected\ Wave\ Height$$

$$MN = Mean$$

$$\sigma = Standard\ Deviation$$

$$N = Total\ number\ of\ waves\ with\ period\ T_p in\ 3\ hours$$

$$\alpha = Probability\ that\ the\ extreme\ value\ exceeds\ a\ specified\ value$$

The workability can then be expressed as a function of the probability and amplitude of these waves in a chosen time scale. In the example above, the time scale is three hours which is a common choice.

4.5 Frequency Domain

When modelling a system in the frequency domain, the response of the vessel is calculated using the transfer function as follows:

$$S_x(\omega) = |H(\omega)|^2 \cdot S_z$$

A transfer function can be made of the relative distance between the load and the deck, as explained in the next part of the chapter. The disadvantage of this method, however, is that nothing can be derived about the speed of of the load with respect to the deck. In order to be able to do this, the frequency domain plus method is developed.

4.6 Frequency Domain Plus Method

Another, perhaps more refined method to determine the workability of the operation, is the Frequency Domain Plus method, so called because it has better predictive capabilities than just a frequency domain method. Here, instead of beginning the analysis with a wave scatter diagram and a JONSWAP wave spectrum, we begin with a directional energy spectrum from ocean weather data:

$$E(\omega,\alpha)$$

Which we transform to a wave spectrum for each directional interval α to get:

$$S_Z(\omega,\alpha)$$

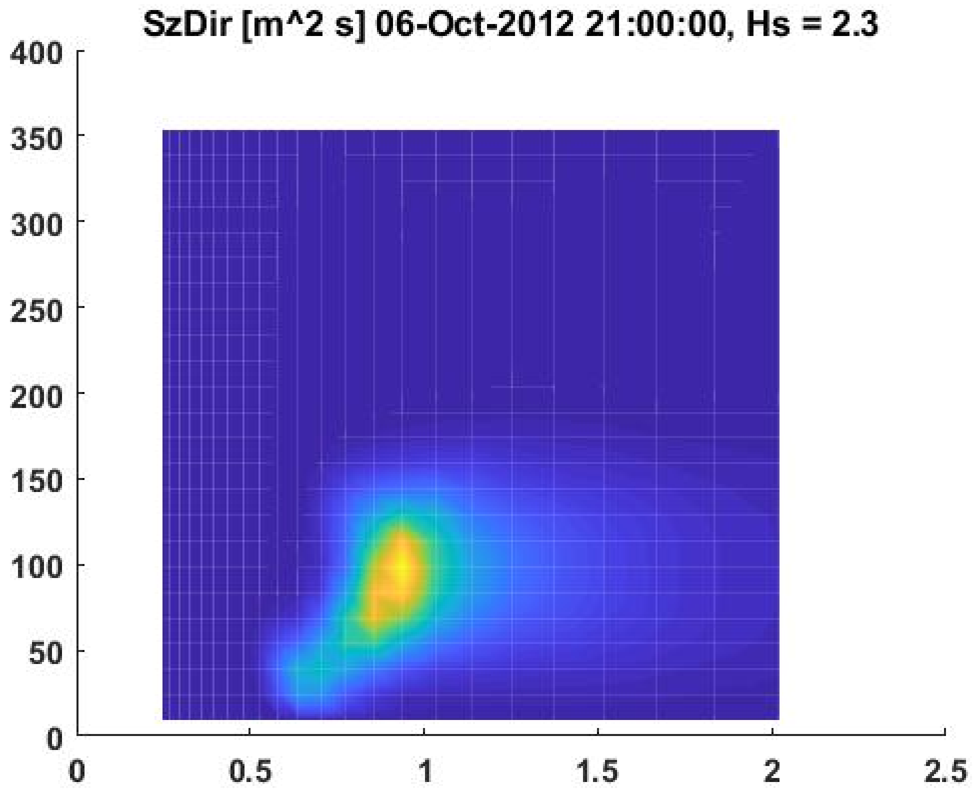


Figure 4.6: Sz for a record in october

By adding a random phase shift ε to all waves for each frequency and direction, we get the surface elevation in the frequency domain:

$$Z(\omega,\alpha)$$

And, using the transfer function, we obtain the response:

$$X(\omega,\alpha) = |H(\omega|^2 . Z(\omega,\alpha)$$

Now, by using Fourier (the inverse Fast Fourier Transformation – iFFT) we obtain the surface elevation as well as the response in the time domain:

$\zeta(t)$ and $x(t)$

The great advantage of this method is that the method of adding random phases to each frequency allows for the creation of as many “real”, time domain wave records as one wants. Being able to produce infinite amounts of wave records quickly, greatly increases the significance of the statistical analysis that is done post processing.

Another advantage is that, in the time domain, we can assess not only the chances of collision between the load and the deck occurring, but also the speed with which this happens. This means we can “refine”, the risk assessment by differentiating between dangerous, high impact collisions and relatively safe, low-impact collisions allowing for more useful workability assessments.

4.6 Probability Distributions

The probability distributions relevant to this analysis are also analysed. The surface elevation is Gaussian distributed and will not be treated in detail, but it is important to note that the wave realisations done in MatLab have a surface elevation that fit the normal distribution as well.

The wave peaks are Rayleigh distributed [Lord Rayleigh, 1870] when the frequency band is relatively narrow. Its given by:

$$f(x;\sigma) = \frac{x}{\sigma^2} e^{-x^2/(2\sigma^2)}, \quad x \geq 0,$$

And depicted below for several values of sigma, which denotes the scale parameter.

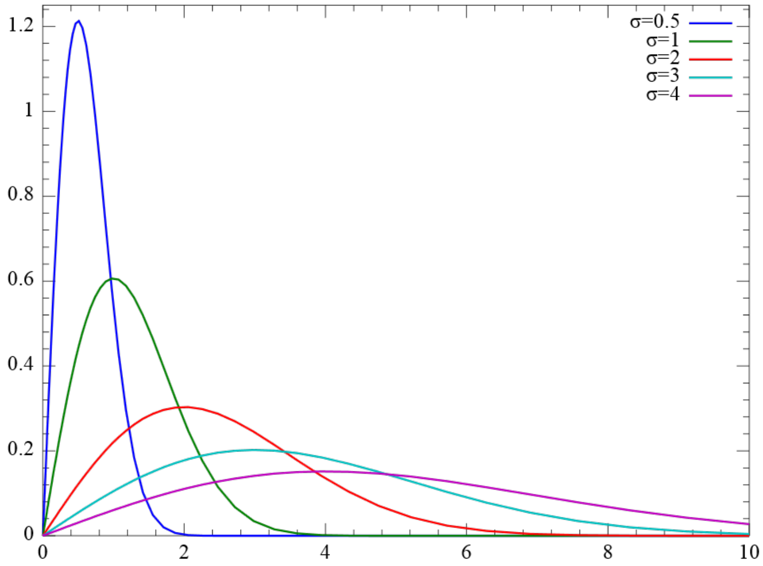


Figure 4.7: Rayleigh Distribution

As we wil see further on in this thesis, the impacts of the load and the deck seem to fit a Weibull distribution [Weibull, 1951]. A Weibull distribution has two parameters, a shape parameter (k) and a scale parameter λ. Rayleigh distribution is in fact a Weibull distribution with a specific value for k and λ:

$$f(x;\lambda,k) = \begin{cases} \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} e^{-(x/\lambda)^k} & x \geq 0, \\ 0 & x < 0, \end{cases}$$

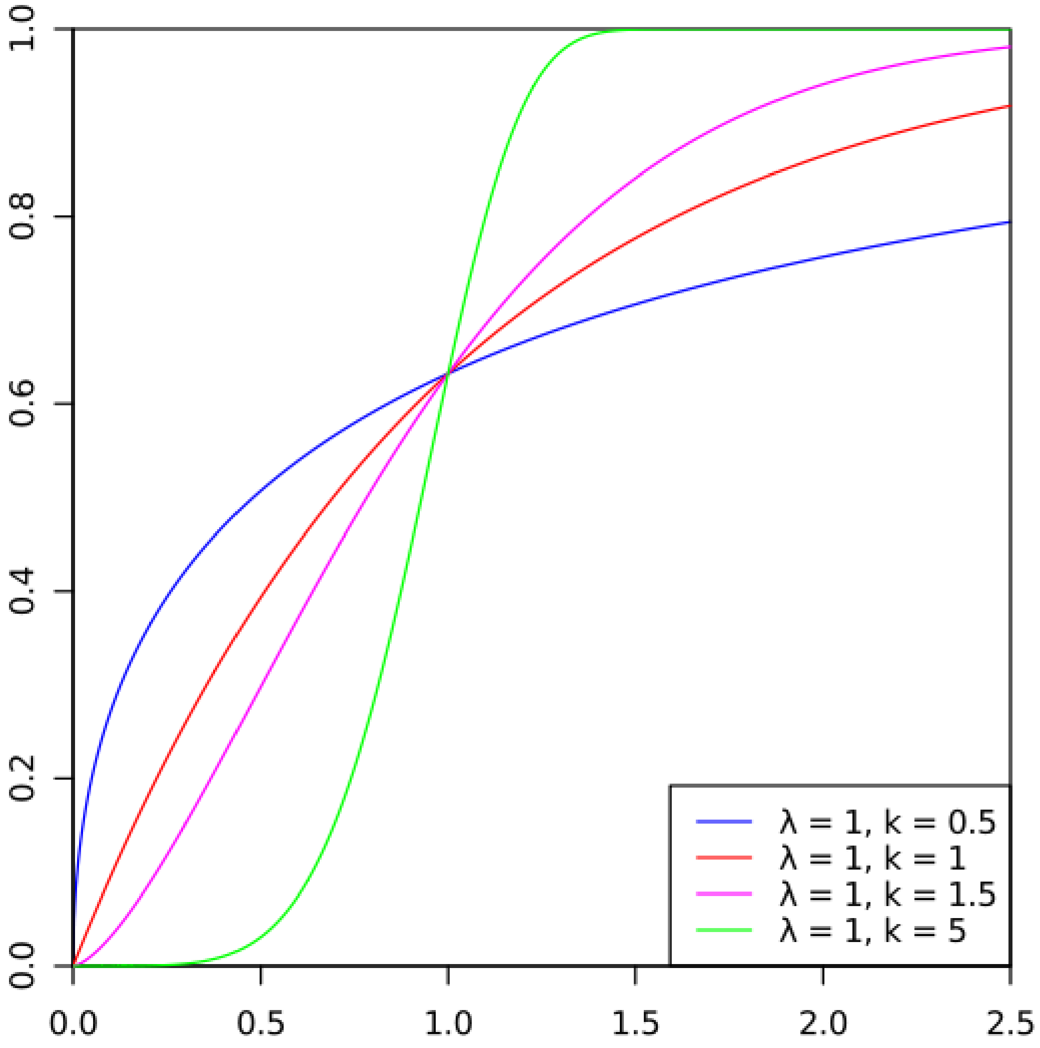


Figure 4.8: Probability Density Function of several Weibull Distributions

Chapter 5

Model

5.1 Equations of Motion

The equations of motion (in time domain),

$$\bar{\bar{M}}\ddot{\bar{x}}(t) + \bar{\bar{K}}\bar{x}(t) = \bar{f}(t)$$

With,

$$\bar{x} = \hat{\bar{x}}e^{i\omega t}$$

$$\ddot{\bar{x}} = -\omega^2\hat{\bar{x}}e^{i\omega t}$$

Can be written in the frequency domain,

$$\{-\omega^2\bar{\bar{M}} + \bar{\bar{K}}\}\bar{X}(\omega) = \bar{F}(\omega) = \bar{F}_{rad} + \bar{F}_{diffr}$$

And with

$$\bar{F}_{rad} = A\omega^2X - i\omega BX$$

We get,

$$\{-\omega^2(M + A(\omega)) + i\omega B(\omega) + K\}\bar{X} = \bar{F}_{diffr} = \bar{H}_{FZ}(\omega, \boldsymbol{\alpha}!)Z(\omega)$$

Which becomes,

$$RAO = H(\omega, \alpha) = \frac{\bar{X}}{Z} = \frac{H_{FZ}}{-\omega^2(M + A) + i\omega B + K}$$

Since we are dealing with a system involving two floating bodies that are coupled, the motion equations take the form,

$$\left\{-\omega^2\begin{bmatrix}\overline{\overline{M_1}} + A_1 & A_{12} \\ A_{21} & \overline{\overline{M_2}} + A_{22}\end{bmatrix} + i\omega\begin{bmatrix}B_{11} & B_{12} \\ B_{21} & B_{22}\end{bmatrix} + \begin{bmatrix}K_{11} & K_{12} \\ K_{21} & K_{22}\end{bmatrix}\right\}\begin{bmatrix}\bar{X}_1 \\ \bar{X}_2\end{bmatrix} = \begin{bmatrix}H_{FZ1} \\ H_{FZ2}\end{bmatrix}Z$$

In which each M, A, B, K are 6 x 6 matrices.

In order to derive the relative response of the distance between the MC-Class deck and the load in the crane of the Aegir, we first translate the motions at the respective CoG of the vessels to the points of interest; the lower part of the load and the deck at the location of the reel:

$$\bar{x}_R = \bar{x}_1 + R_1\overline{\varphi}_1$$

$$\bar{x}_D = \bar{x}_2 + R_2\overline{\varphi}_2$$

The distance between the deck and the load, i.e. the gap then becomes,

$$\overline{\Delta x} = \bar{x}_R - \bar{x}_D = \bar{x}_1 - \bar{x}_2 + \bar{\bar{\bar{R}}}_1\overline{\varphi}_1 - \bar{\bar{\bar{R}}}_2\overline{\varphi}_2$$

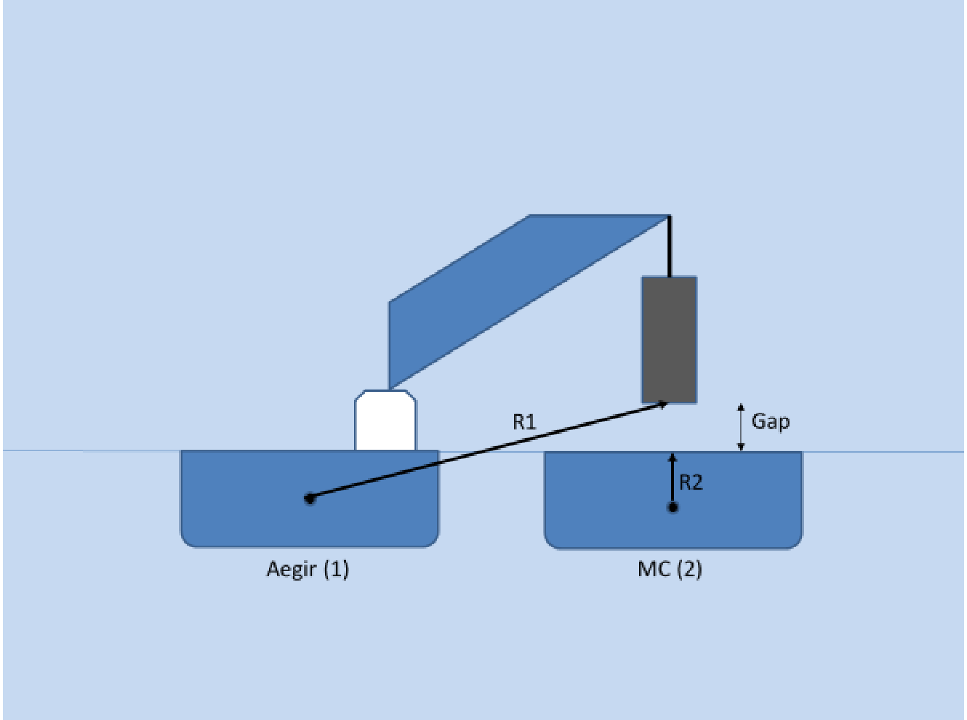


Figure 5.1: Visualization of the gap

5.2 Ansys AQWA

Ansys AQWA is used to import the vessel's geometry files. For each step, having different relative positions of the vessels, Ansys AQWA calculates the A, B and K matrices of the system as well as the transfer functions. These then serve as input for Matlab to determine the response of the gap between load and deck.

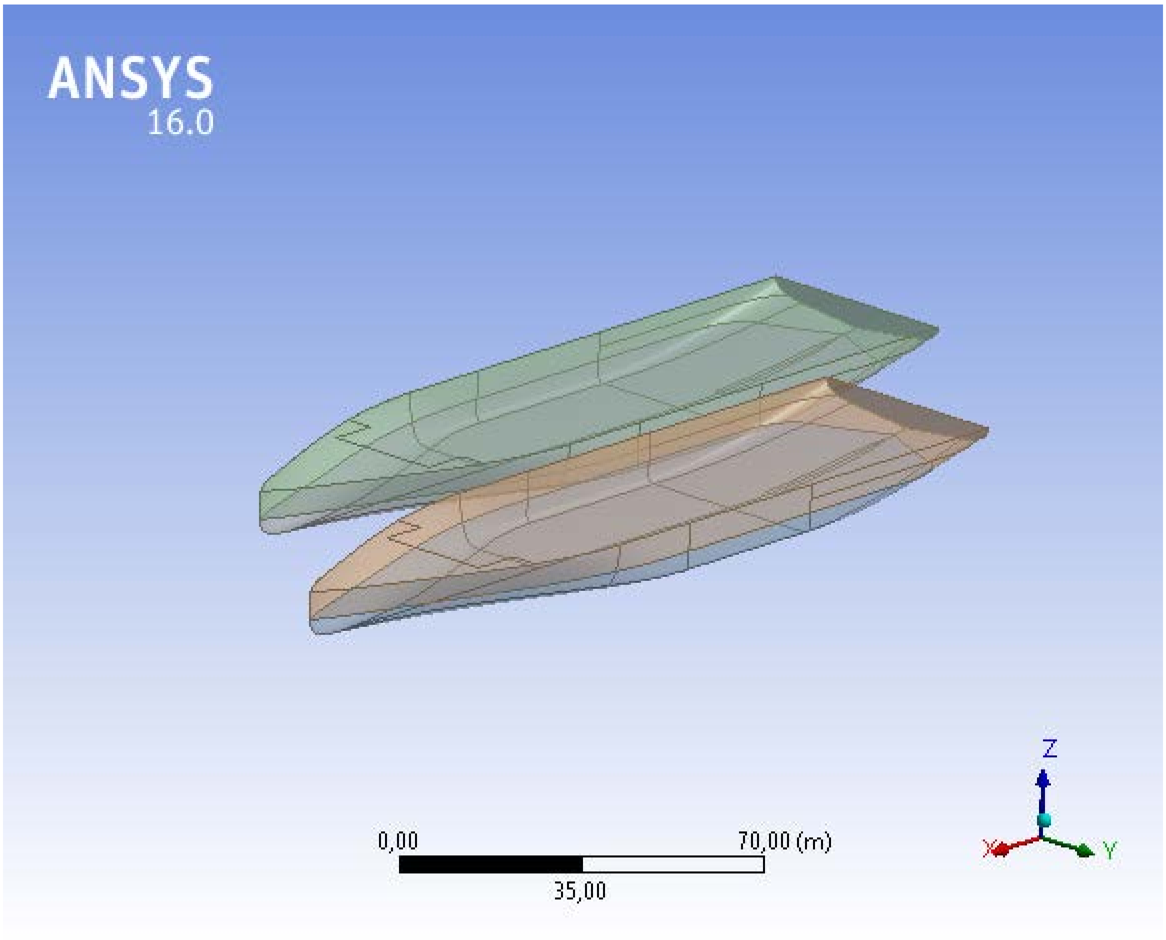


Figure 5.2

For the Aegir model, the OSV model was scaled up to the approximate proportions of the Aegir, as access to a 3D model of the Aegir was restricted.

5.3 MATLAB

Next, MATLAB is used to read the LIS file produced by AQWA in order to do further analysis. The transfer functions are used to create a transfer function of the gap between the reel and the deck:

$$H_{gap}(\omega) = H_{Reel}(\omega) - H_{Deck}(\omega)$$

Also, as briefly touched upon earlier, the wave spectrum deduced from a 3 hour wave record is subdivided into 1000 frequency bands and 24 wave directions. For each combination of these, a wave is created with a random phase in order to create a surface elevation realisation in the time domain by superposition of aforementioned waves. This can be done many times and very quickly, greatly increasing the number of realisations based on a wave record that contains only the surface elevation and frequency information.

All these realisations can then be used to determine how different sea states affect the gap size. Doing this for different initian gap sizes, one can also assess the influence of the crane's hoisting speed on the probability of collision. And as we have a realisation in the time domain, we can also determine the speed with which ach collision occurs, allowing us to differentiate between harmless, low-velocity impacts and damaging, high velocity impacts.

The great advantage is that this allows for a very quick and "dynamic" predictive insight into the workability of the lifting operation.

Below, the result of such a realisation is shown: The gap between the load and the deck is shown as a response of the system to one wave realisation. The negative values here imply that the deck and the load would often collide under these circumstances. In the next chapter we delve further into this and take into consideration the need of a small time window during which the load is lifted to a chosen, safe level. When the load has been lifted above deck, say, 1 m, the record below would move upwards, decreasing the amount of impacts as well as the speed with which the remaining impacts occur.

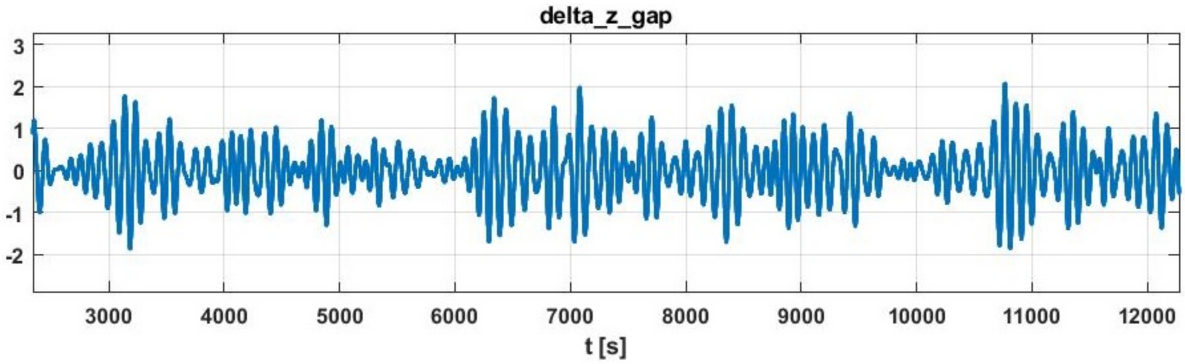


Figure 5.2: Gap size as result of realisation based on Hs = 2,3 m wave record

Chapter 6

Workability

With the operation, criteria and the model having been described in the previous chapters, this chapter will present the results of the workability assessment for the operation as a whole and for each step individually. It should be noted again that the method used to determine the workability is not the same for each step. This is due mainly to the fact that the decision process depends on different criteria for each step, but also because the consequences of failure are very different. As a reminder, the criteria for each step can be found at the end of chapter 3.

It is important to keep in mind also that correctly assessing the workability of an offshore operation serves two puposes. First and foremost, risks to people and goods are reduced by more accurate predictions of unsafe situations. Secondly, insight into the workability, and what influences is necessary in order to determine how to increase workability in the future, which in turn increases competitivesness. Considering that the environmental conditions are judged to be either safe or unsafe, and that a decision is made to either proceed or not proceed with an operation, four working environments or categories arise:

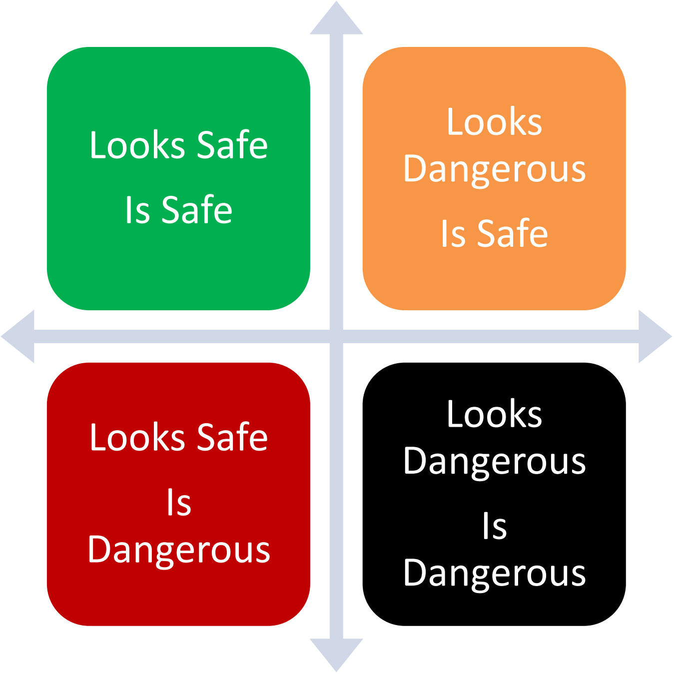


Figure 6.1. Maximising safety and profit

In this figure, in the top left corner, the green area is the area in which operations tend to take place. It is correctly assessed as being safe. Work proceeds and income is generated.

The orange area is incorrectly assessed as being unsafe i.e. a “false positive”. This represents lost opportunity as, in reality, operations could have taken place safely under these conditions but they were wrongfully deemed too dangerous. This could happen when safety criteria are not met when in fact the environmental conditions are of a type that allow for a safe execution of the operation. It is shown in the remainder of this chapter, for example, that the response of the gap is to a very large extent dpendent on the wave period. For higher wave frequencies, it is therefore safe, according to data generated with this model, to proceed with the lift even if the wave height is above a typical criterium of 2,5 m. Anticipating this could therefore increase the green zone and shift it to the right, thereby decreasing the orange area. This amounts to a gain in the operational window.

In red, the conditions have been incorrectly marked as safe. This is the “false negative” that needs to be avoided. In practice this means that it should be minimised so that the likeliness of this occuring is infinitely small. This is where accidents happen. Data generated with my model doesn’t show a conflict here with standard safety criteria practices.

In black is the area that is correctly perceived as dangerous. No work can or should be done in this area.

It is in the interest of the party trying to decide whether to proceed with an operation or not, both in terms of avoiding accidents as well as economically, to maximise the green area. A larger green area, especially when compared to a competitor, implies both a better, more precise judgment of the risks, as well as more generated income.

Therefore, for the first step it is enough to determine for which sea states this step is feasible. For the third step, however, a more detailed analysis of the chances of the load and deck colliding are necessary and a much more precise workability analysis is needed.

Before proceeding to an analysis for each step of the operation, consider the figures below depicting the variation in significant wave height throughout a year (fig 6.1) and how the workability changes for a few commonly used maximum significant wave heights (fig. 6.2) to get an idea of the extent to which the seasons affect work in the North Sea. Significant wave heights of 1,5 m, 2 m and 2,5 m metres are common indicators of various types of operations that can be done offshore.

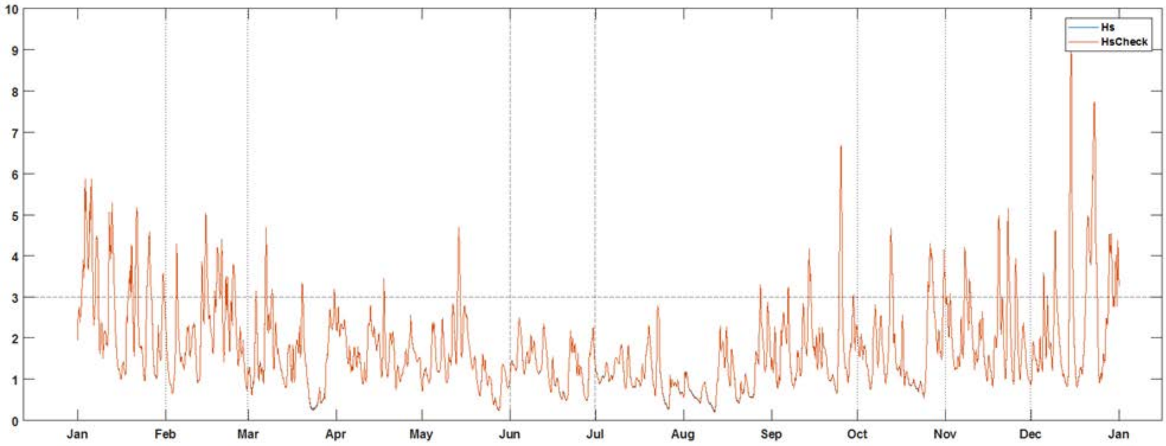


Figure 6.2. Recorded sea states (Hs) in 2012

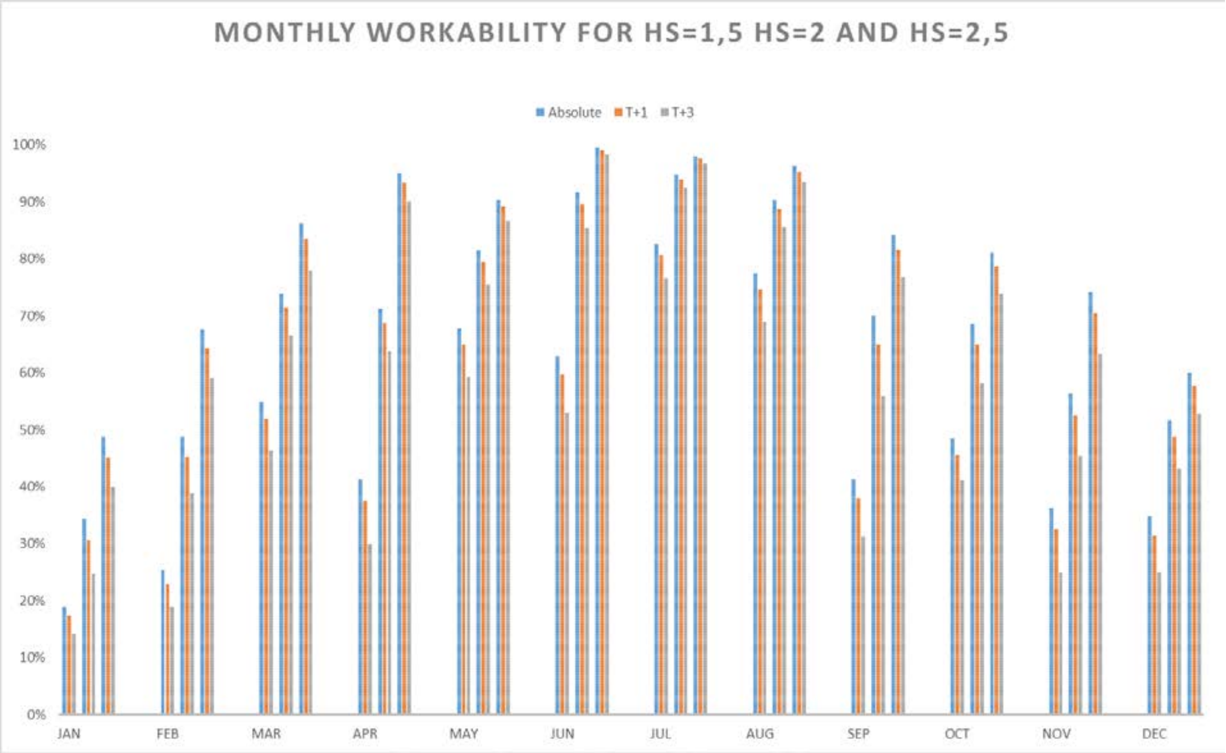


Figure 6.3 Workability for different Hs criteria.

The above figure also takes into account the effect of the next sea state(s) on workability. Note the enormous differences in "uptime" between, say, January, during which the workability is around 25% for a maximum significant wave height of 2 m when also taking into account the possible higher waves in the next 3 sea states, and June, for which the equivalent workability is almost 90%.

Below are the results for the workability for every step in the operation. When multiple criteria apply to one step, the limiting influence of all criteria on the workability will be assessed to determine which one is critical.

6.1 Arrival

The first criterion (1a) related to the arrival and (re)positioning of the MC next to the Aegir is the maximum significant wave height of 3 m. As only wave height is considered, a wave scatter diagram provides enough information to roughly determine a workability.

We find that a total of 2582 out of 2928 records have a sea state with a significant wave height of 3 m. This equals around 88 % of all the records. When accounting for the seasonal differences, we find that the differences are very large.

Month	JAN	FEB	MRT	APR	MEI	JUN	JUL	AUG	SEP	OKT	NOV	DEC
Hs < 3 m	59%	78%	94%	99%	97%	100%	100%	99%	92%	87%	85%	68%

Figure 6.4: Percentage of sea states with Hs < 3 m

6.2 First Hook-on

For the hook-on, the first criterion that applies is similar to the one applied to Step 1, the only difference being that the maximum wave height cannot exceed 2,5 m. For the whole year, the absolute workability (when accounting just for this criterion) is 82%.

Month	JAN	FEB	MRT	APR	MEI	JUN	JUL	AUG	SEP	OKT	NOV	DEC
Hs < 2,5 m	49%	68%	86%	95%	90%	100%	98%	6%	84%	81%	74%	60%

Figure 6.5: Percentage of sea states with Hs < 2,5 m

Now the motions of the crane and the top of the reel are considered. A transfer function of the difference between these two points, one attached to the Aegir and the other to the MC, is made to determine the relative motions. For details, see 6.3 below.

6.3 First Lift

To assess the workability of the most critical step in the operation, we have to consider not just the criteria of the previous step (that are largely also present for this step, as explained in chapter 3), but also take a closer look to the stochastics surrounding a possible collision of the reel and the deck.

Using the method described in the previous chapters, we can generate, for a large number of simulations, a time record for the relative distance between the load and the deck, the gap. Doing this using a particular three-hour time record, with a known sea state, the number of impacts can also be related to the initial gap height. For the first record, beginning January 1, 2012 and having a significant wave height of 1,95 m, this gives the impact velocity vs gap size as follows.

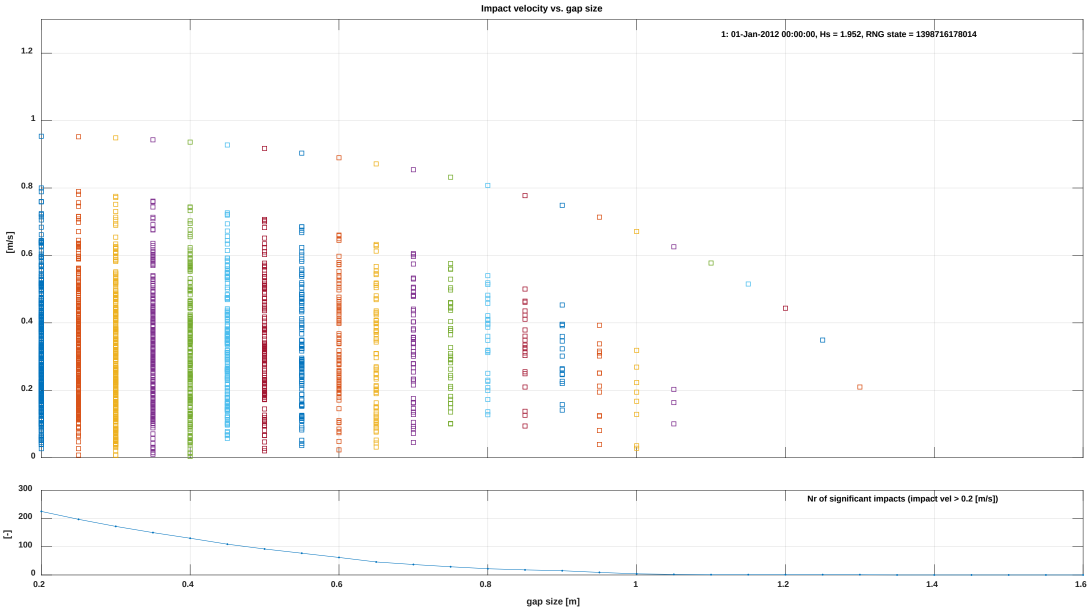
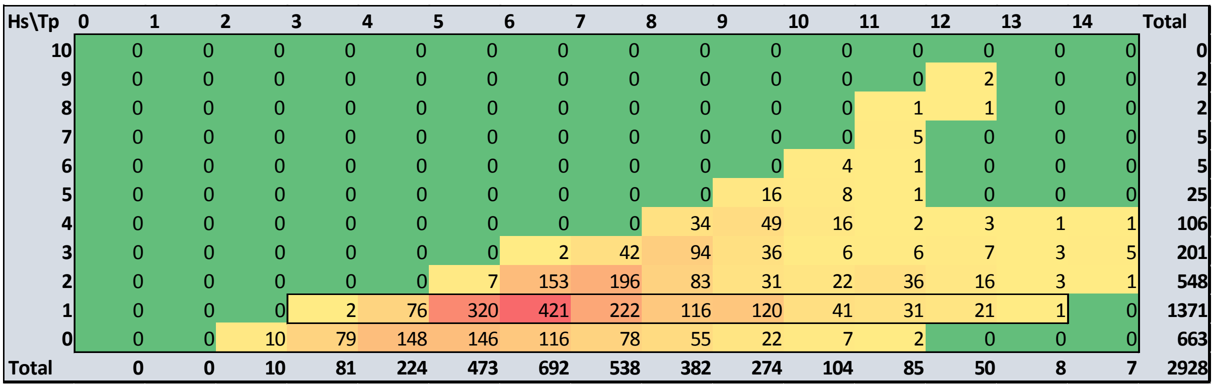


Figure 6.6: Impacts and their velocities for a number of initial gap sizes

At first sight, one can clearly see that the number of impacts declines strongly with an increasing initial gap size. This is all the more true if we disregard the low velocity impacts. Here, with an initial gap of 1 m, we observe a total of 9 impacts of the reel with the deck. Of these impacts, four occur with a velocity above 0,2 m per second.

In order to gain a better understanding of the relations between wave height, initial gap size and impact velocity, we must generate enough response data such as in the graph above to be able to draw statistically significant conclusions and assess the impact on overall workability.

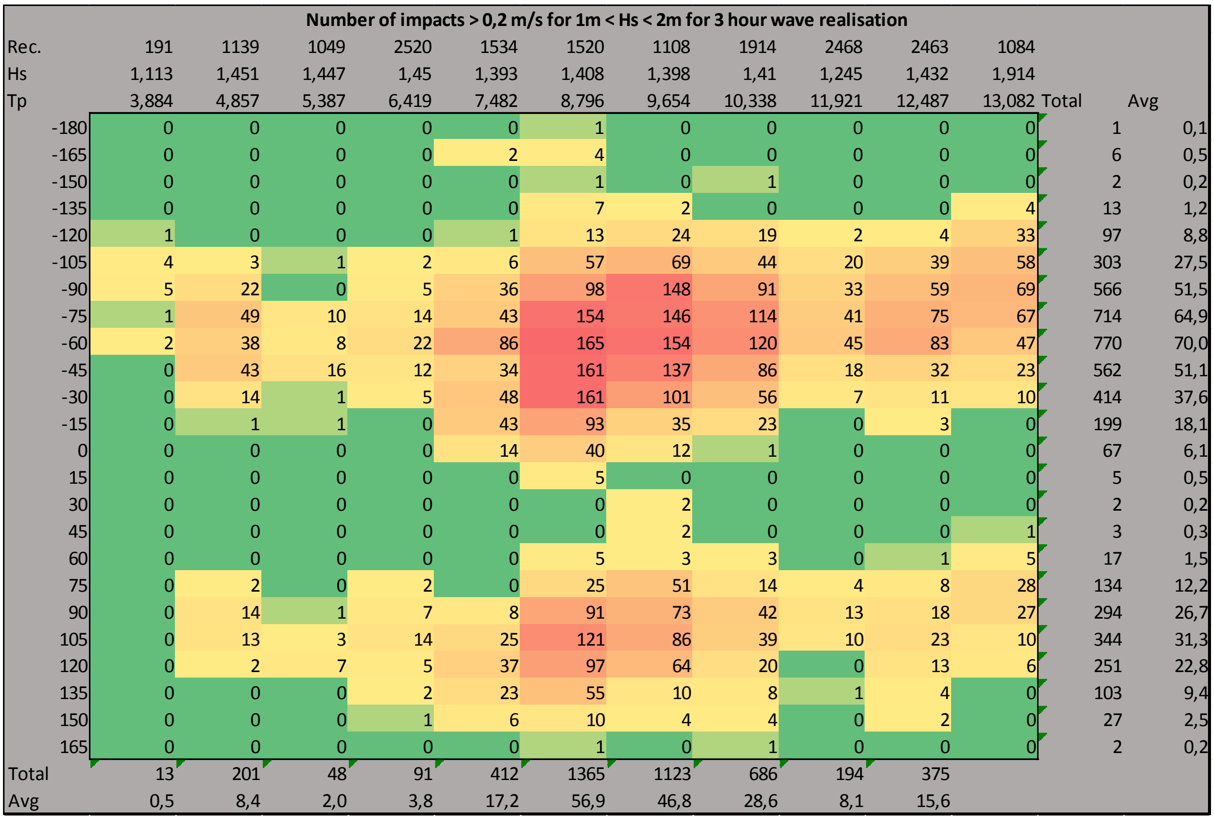
In order to assess the workability, the wave scatter diagram is used to determine the number of impacts for each sea state. This is done for all wave directions in 15 deg intervals. Beginning with the wave scatter diagram for the considered area in the North Sea pictured below, we look at results for each of the occuring sea states



Hs\Tp	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2
8	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	2
7	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	5
6	0	0	0	0	0	0	0	0	0	0	4	1	0	0	0	5
5	0	0	0	0	0	0	0	0	0	16	8	1	0	0	0	25
4	0	0	0	0	0	0	0	0	34	49	16	2	3	1	1	106
3	0	0	0	0	0	0	2	42	94	36	6	6	7	3	5	201
2	0	0	0	0	0	7	153	196	83	31	22	36	16	3	1	548
1	0	0	0	2	76	320	421	222	116	120	41	31	21	1	0	1371
0	0	0	10	79	148	146	116	78	55	22	7	2	0	0	0	663
Total	0	0	10	81	224	473	692	538	382	274	104	85	50	8	7	2928

Figure 6.7: Wave scatter diagram

Next we look at the results for these sea states in more detail. The row of sea states at the bottom of the wave scatter diagram produces very impacts at all. It can be found for reference in the appendix. For each sea state with a significant wave height between 1m and 2m that occurs in this area, that is, the second row of sea states in the WSDfrom below, wave realisations have been made to find the number of impacts. The number of high velocity impacts for each wave direction is displayed below for three hour wave realisations.



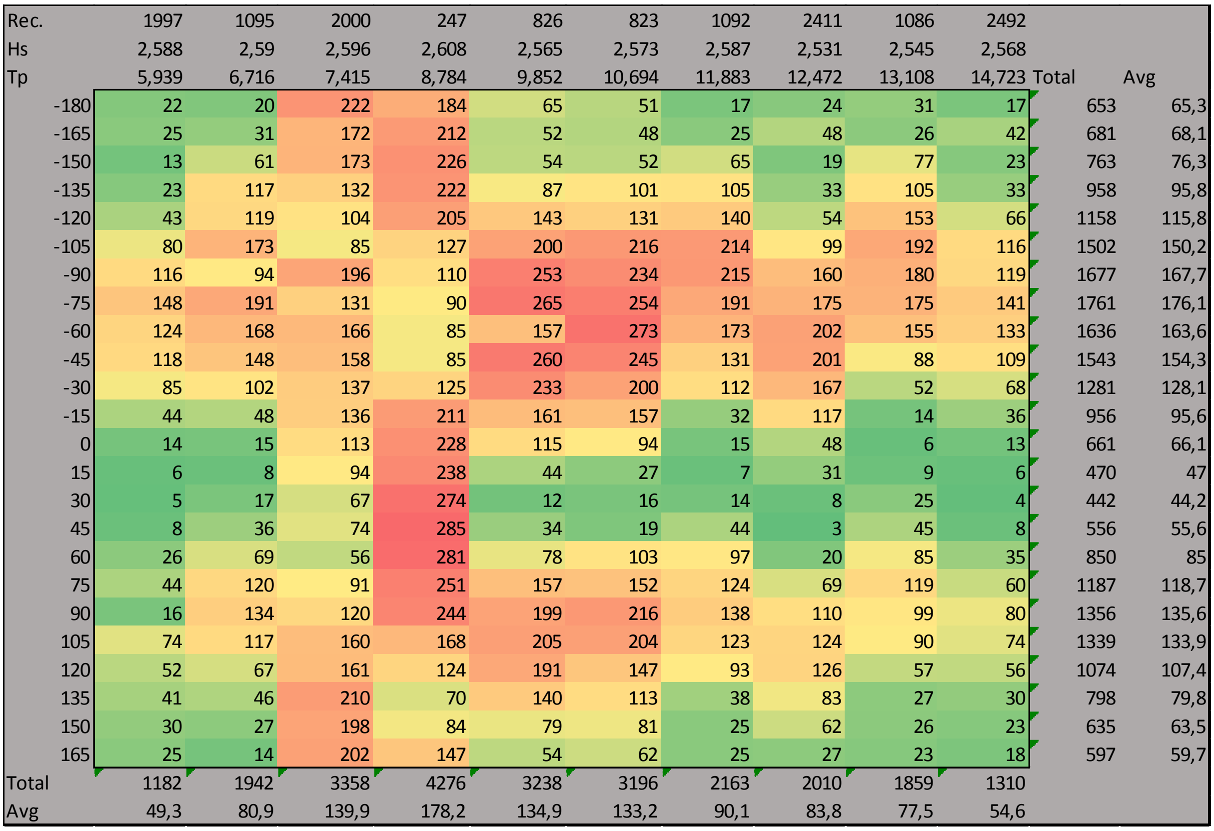
Number of impacts > 0,2 m/s for 1m < Hs < 2m for 3 hour wave realisation

Rec.	191	1139	1049	2520	1534	1520	1108	1914	2468	2463	1084		
Hs	1,113	1,451	1,447	1,45	1,393	1,408	1,398	1,41	1,245	1,432	1,914		
Tp	3,884	4,857	5,387	6,419	7,482	8,796	9,654	10,338	11,921	12,487	13,082	Total	Avg
-180	0	0	0	0	0	1	0	0	0	0	0	1	0,1
-165	0	0	0	0	2	4	0	0	0	0	0	6	0,5
-150	0	0	0	0	0	1	0	1	0	0	0	2	0,2
-135	0	0	0	0	0	7	2	0	0	0	4	13	1,2
-120	1	0	0	0	1	13	24	19	2	4	33	97	8,8
-105	4	3	1	2	6	57	69	44	20	39	58	303	27,5
-90	5	22	0	5	36	98	148	91	33	59	69	566	51,5
-75	1	49	10	14	43	154	146	114	41	75	67	714	64,9
-60	2	38	8	22	86	165	154	120	45	83	47	770	70,0
-45	0	43	16	12	34	161	137	86	18	32	23	562	51,1
-30	0	14	1	5	48	161	101	56	7	11	10	414	37,6
-15	0	1	1	0	43	93	35	23	0	3	0	199	18,1
0	0	0	0	0	14	40	12	1	0	0	0	67	6,1
15	0	0	0	0	0	5	0	0	0	0	0	5	0,5
30	0	0	0	0	0	0	2	0	0	0	0	2	0,2
45	0	0	0	0	0	0	2	0	0	0	1	3	0,3
60	0	0	0	0	0	5	3	3	0	1	5	17	1,5
75	0	2	0	2	0	25	51	14	4	8	28	134	12,2
90	0	14	1	7	8	91	73	42	13	18	27	294	26,7
105	0	13	3	14	25	121	86	39	10	23	10	344	31,3
120	0	2	7	5	37	97	64	20	0	13	6	251	22,8
135	0	0	0	2	23	55	10	8	1	4	0	103	9,4
150	0	0	0	1	6	10	4	4	0	2	0	27	2,5
165	0	0	0	0	0	1	0	1	0	0	0	2	0,2
Total	13	201	48	91	412	1365	1123	686	194	375			
Avg	0,5	8,4	2,0	3,8	17,2	56,9	46,8	28,6	8,1	15,6			

Figure 6.8: Impacts for 1 m< Hs < 2m

As is clear from the above table, the most impacts occur for waves coming from -60 to -90 degrees (the top red region) with another “peak”at the 90 deg to 105 deg region. These are the beam waves. The wave period for which most impacts occur is between 8 and 10 seconds.

The same table with data for significant wave heights between 2 m and 3 m looks somewhat different. The two areas corresponding to the wave directions mentioned above are still present, but the difference with the surrounding area, i.e. the impacts caused by wave from different wave angles is not as large. Also visible is the relatively high number of impacts occuring near the natural frequency. This particular column corresponds to a wave record with a period centered around 8,784 sec.



Rec.	1997	1095	2000	247	826	823	1092	2411	1086	2492		
Hs	2,588	2,59	2,596	2,608	2,565	2,573	2,587	2,531	2,545	2,568		
Tp	5,939	6,716	7,415	8,784	9,852	10,694	11,883	12,472	13,108	14,723	Total	Avg
-180	22	20	222	184	65	51	17	24	31	17	653	65,3
-165	25	31	172	212	52	48	25	48	26	42	681	68,1
-150	13	61	173	226	54	52	65	19	77	23	763	76,3
-135	23	117	132	222	87	101	105	33	105	33	958	95,8
-120	43	119	104	205	143	131	140	54	153	66	1158	115,8
-105	80	173	85	127	200	216	214	99	192	116	1502	150,2
-90	116	94	196	110	253	234	215	160	180	119	1677	167,7
-75	148	191	131	90	265	254	191	175	175	141	1761	176,1
-60	124	168	166	85	157	273	173	202	155	133	1636	163,6
-45	118	148	158	85	260	245	131	201	88	109	1543	154,3
-30	85	102	137	125	233	200	112	167	52	68	1281	128,1
-15	44	48	136	211	161	157	32	117	14	36	956	95,6
0	14	15	113	228	115	94	15	48	6	13	661	66,1
15	6	8	94	238	44	27	7	31	9	6	470	47
30	5	17	67	274	12	16	14	8	25	4	442	44,2
45	8	36	74	285	34	19	44	3	45	8	556	55,6
60	26	69	56	281	78	103	97	20	85	35	850	85
75	44	120	91	251	157	152	124	69	119	60	1187	118,7
90	16	134	120	244	199	216	138	110	99	80	1356	135,6
105	74	117	160	168	205	204	123	124	90	74	1339	133,9
120	52	67	161	124	191	147	93	126	57	56	1074	107,4
135	41	46	210	70	140	113	38	83	27	30	798	79,8
150	30	27	198	84	79	81	25	62	26	23	635	63,5
165	25	14	202	147	54	62	25	27	23	18	597	59,7
Total	1182	1942	3358	4276	3238	3196	2163	2010	1859	1310		
Avg	49,3	80,9	139,9	178,2	134,9	133,2	90,1	83,8	77,5	54,6		

Figure 6.9: Impacts for varying sea states and wave directions, wave height between Hs = 2 m and Hs = 3 m

Given that there are a lot of wave records with significant wave heights between 2 m and 3 m, it has allowed for a comparison of many ave records with similar wave heights (in this case close to 2,5 m) but with different wave periods. An interesting result is that the number of impacts increased 3,5 times for the same wave height when comparing the record with a period 5,9 sec with the wave record having a period of 8,8 seconds.

If we look at the transfer functions of the crane, the deck and the gap itself, we can see the relation between the wave period and the higher number of impacts. Below is a figure of the gap's transfer function. We see peaks at 6,3 seconds and 7,8 seconds, which is significantly lower than the 9,8 and 10,7 seconds that produce the peaks in number of impacts for a wave direction of -75.

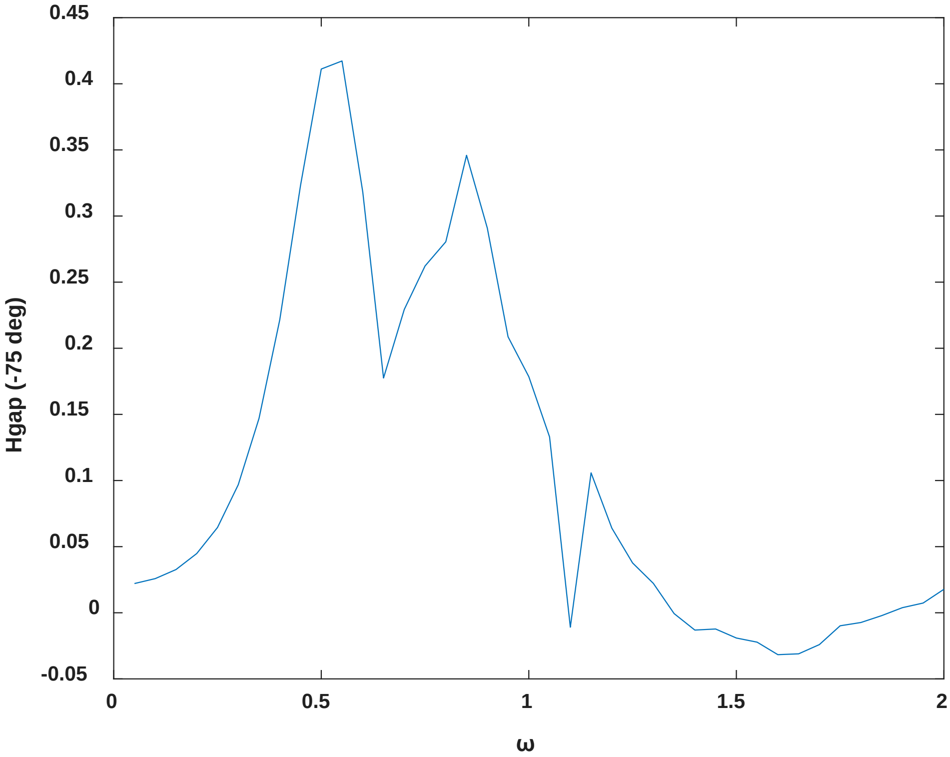


Figure 6.10: Transfer function of the gap between reel and deck

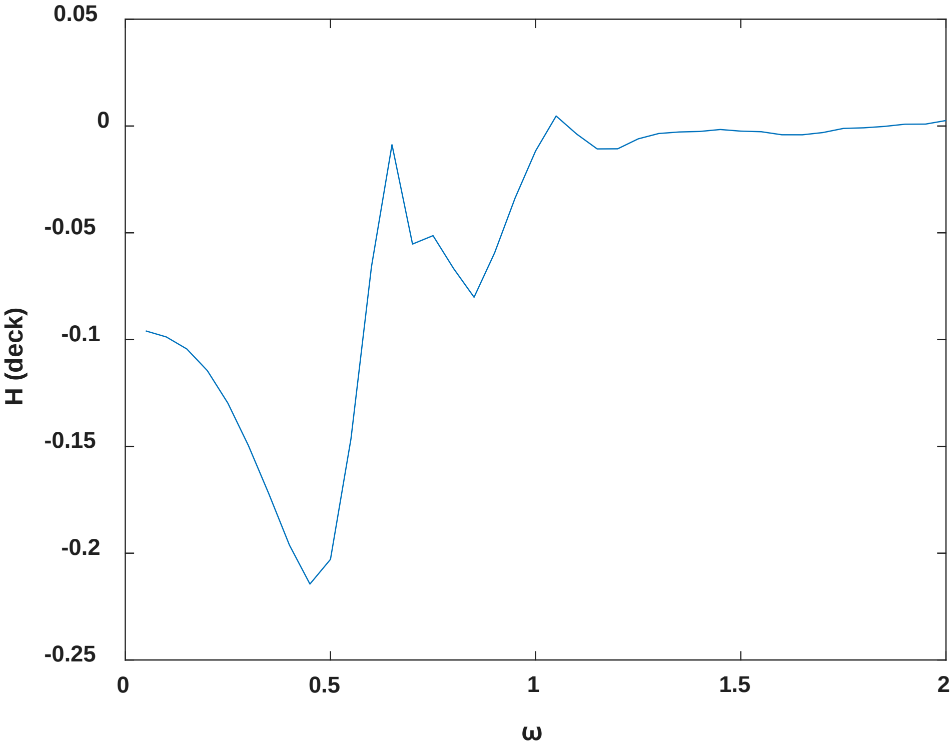


Figure 6.11: Transfer function of the deck at -75 deg

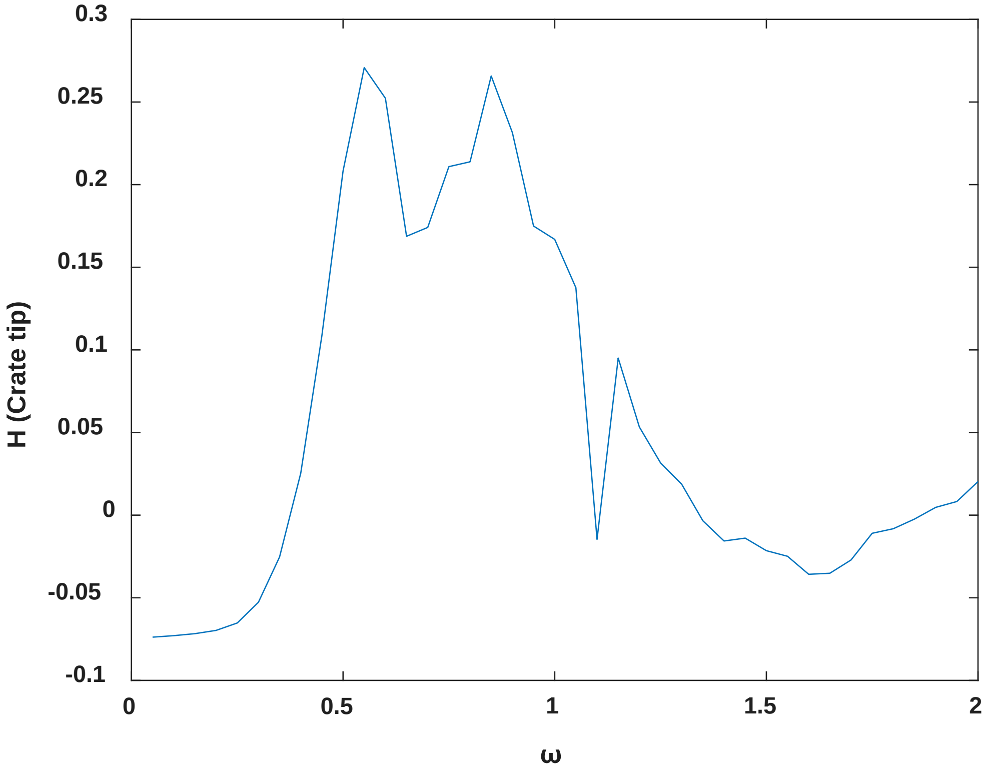


Figure 6.12: Transfer function of the crane tip at -75 deg

In the last figure, we see acloser relationship with the number of impacts in the table above. This can, in all likelihood be attributed to the fact that the crane tip's movements are amplified by the large distance to the centre of gravity of the Aegir.

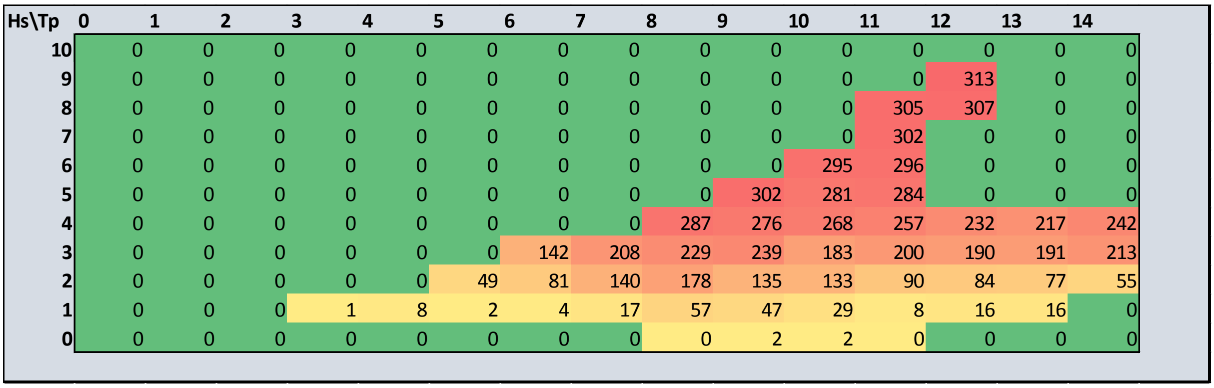
The number of impacts that exceed a velocity level that causes damage is a good measure to assess the workability. Given that the Aegir crane's hoisting speed is estimated to be close to 0,1 m/s, we are now left to determine whether the number of "would-be dangerous collisions" would allow us to lift the load to a safe height between two such events occuring. Assuming first that the dangerous impacts are spread evenly during such a three-hour record allows us to use the average amount of time between such collisions as the time during which the load must lifted to safety.

A 1 m gap is reached after hoisting for 30 seconds. Using different safety margins, say, five and ten times this duration compared against the average time between dangerous collisions allows us to determine a workability with clearly differentiated safety levels.

n damaging impacts	5	10	15	20	25	30	35	40	45	50	55	60
impact time interval	600	327	225	171	138	116	100	88	78	71	64	59

Figure 6.10: Division of nterval size into safe and unsafe values

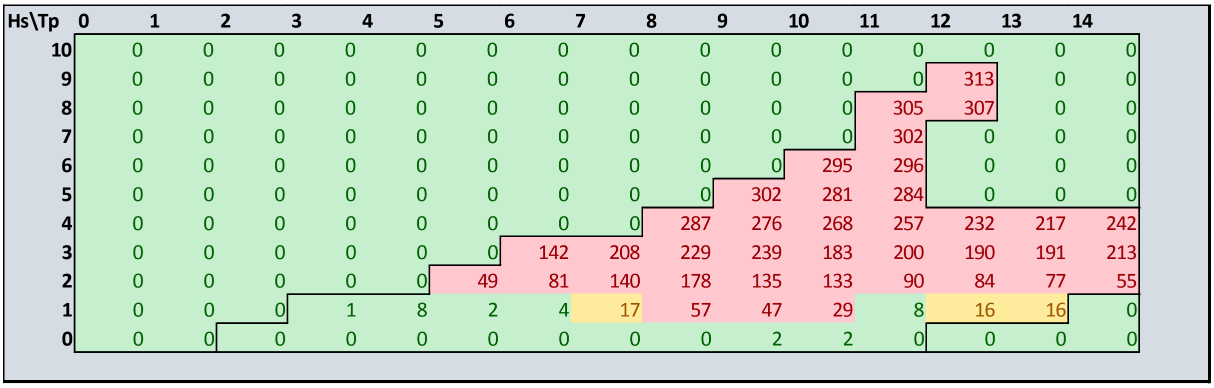
After producing the same tables for the heigher sea states as well, one can see the number of high velocity impacts for all sea states.



Hs\Tp	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	313	0	0
8	0	0	0	0	0	0	0	0	0	0	0	305	307	0	0
7	0	0	0	0	0	0	0	0	0	0	0	302	0	0	0
6	0	0	0	0	0	0	0	0	0	0	295	296	0	0	0
5	0	0	0	0	0	0	0	0	0	302	281	284	0	0	0
4	0	0	0	0	0	0	0	0	287	276	268	257	232	217	242
3	0	0	0	0	0	0	142	208	229	239	183	200	190	191	213
2	0	0	0	0	0	49	81	140	178	135	133	90	84	77	55
1	0	0	0	1	8	2	4	17	57	47	29	8	16	16	0
0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0

Figure 6.11: Average number of impacts over all wave directions, for each sea state.

When accounting for the time intervals between the impacts counted above, we get a "workability diagram" of all the sea states:

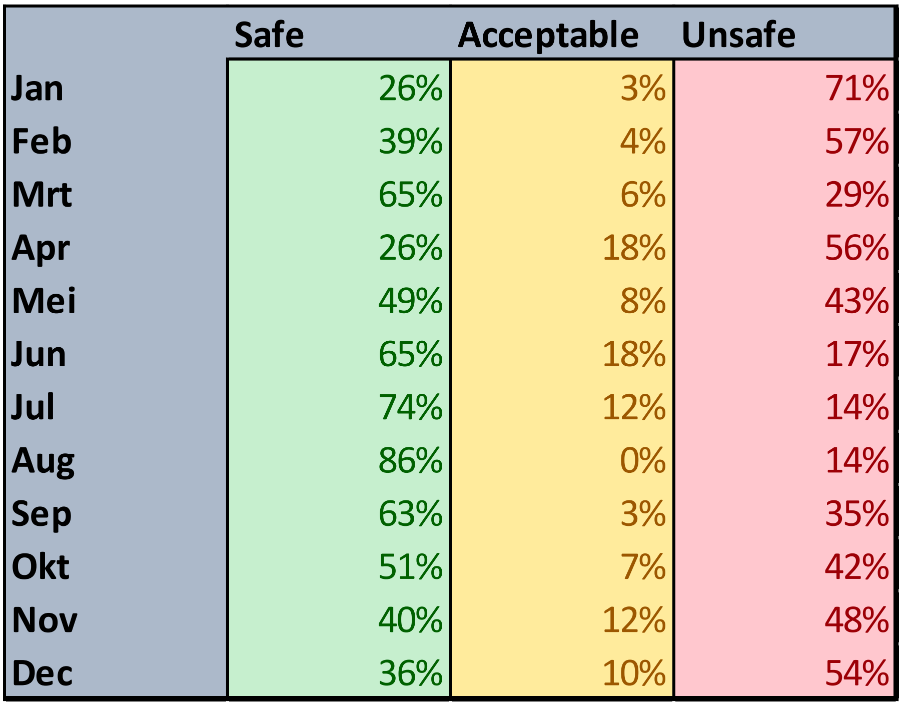


Hs\Tp	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	313	0	0
8	0	0	0	0	0	0	0	0	0	0	0	305	307	0	0
7	0	0	0	0	0	0	0	0	0	0	0	302	0	0	0
6	0	0	0	0	0	0	0	0	0	0	295	296	0	0	0
5	0	0	0	0	0	0	0	0	0	302	281	284	0	0	0
4	0	0	0	0	0	0	0	0	287	276	268	257	232	217	242
3	0	0	0	0	0	0	142	208	229	239	183	200	190	191	213
2	0	0	0	0	0	49	81	140	178	135	133	90	84	77	55
1	0	0	0	1	8	2	4	17	57	47	29	8	16	16	0
0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0

Figure 6.12: Impacts per hour, Safe, Acceptable and too dangerious conditions

Of course, the fact that this is year-round data, and that it doesnt account for differences due to the influence of wave directions not being accounted for in the above table, means more detailed information is needed for the operator deciding whether to go ahead with the lifting of the reel or not to be able to do his work. Note that the zeros outside the marked area are for "non-occuring" (in this OW data set) sea states.

When looked at on a month-to-month basis, we find the following workable percentages of safe, acceptable riskand dangerous sea states for each month:



	Safe	Acceptable	Unsafe
Jan	26%	3%	71%
Feb	39%	4%	57%
Mrt	65%	6%	29%
Apr	26%	18%	56%
Mei	49%	8%	43%
Jun	65%	18%	17%
Jul	74%	12%	14%
Aug	86%	0%	14%
Sep	63%	3%	35%
Okt	51%	7%	42%
Nov	40%	12%	48%
Dec	36%	10%	54%

Figure 6.13: Monthly Lifting Workability

This provides important insight into the feasibility of the lift on a monthly basis, but it's important to note that the wave directions have a big impact. Knowing where the waves will come from in the very near future therefore largely impacts the decision making process.

6.4 Repositioning

The workability of this step depends on the same criteria as the positioning discussed in 6.1. Furthermore, the criteria governing the criteria of the previous step (6.3, the first lift) are much more limiting, the chances of weather conditions occuring at this particular time making the repositioning impossible are extremely unlikely and will not be treated in further detail.

6.5 Second hook-on

Again, determining the workability of this step is the same as in the second step (the first hook-on), the only difference being the difference in relative position of the vessels, as well as the difference in mass and draft caused by the transfer of the first reel onto the Aegir.

6.6 Stochastic Analisys

A further aspect of this method is that a lot of insight is gained into the stochastics of waves, their most probable extremes under given environmental conditions. Also, the stochastics surrounding the number of impacts and, since the wave realisations are in the time domain, the velocity at which those predicted impacts occur.

When plotting the velocities of each impact for a given initial gap size, we find that it quite neatly follows a Weibull distribution:

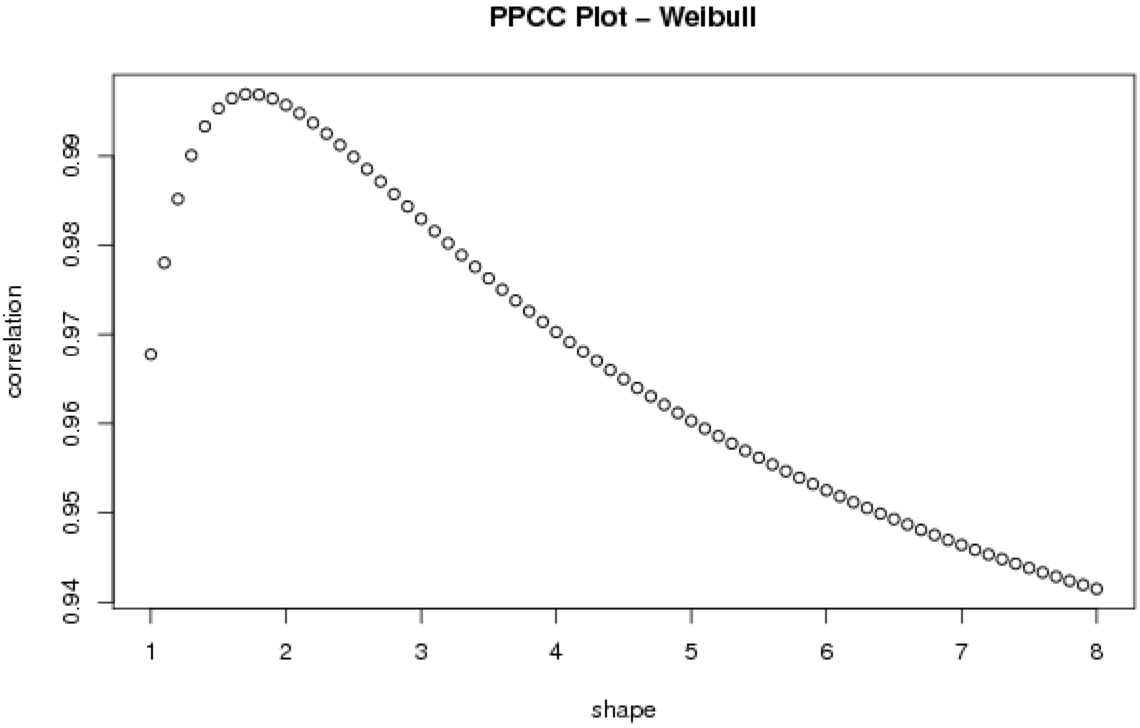
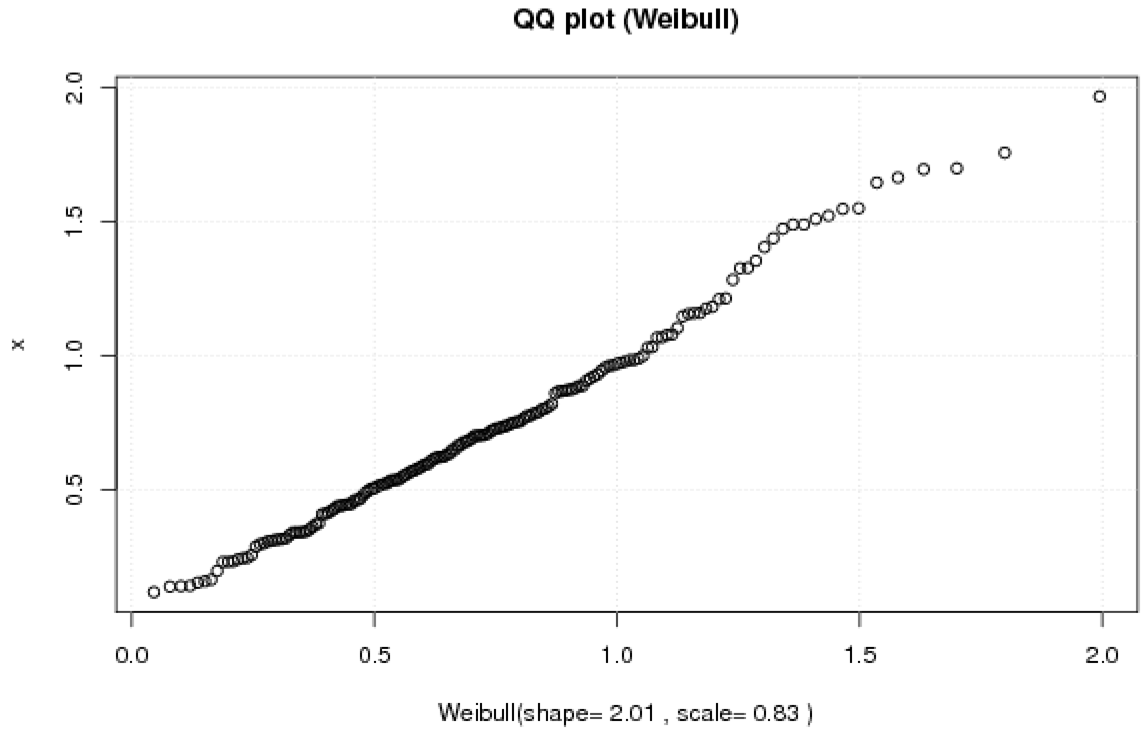


Figure 6.14: Distribution of impact velocities. Hs = 2,5; T = 7,4, wave dir -60 deg



Figuur 6.15: Corresponding QQ plot (Hs = 2,5; Tp =7,4; wave dir -60 deg)

The same distribution fitting and QQ plots have been produced for all considered sea states. The shape and scale factors, as well as the standard deviations of these distributions is given in the table below. The shape of the distribution appears to be very constant. It is, in fact, very close to 2 throughout the different sea states, even comparatively high ones.

	Hs 1 - 2		**-75 deg**									**AVG**
Rec	191	1139	1049	2520	1534	1520	1108	1914	2468	2463	1084	
Hs	1,11	1,45	1,45	1,45	1,39	1,41	1,40	1,41	1,25	1,43	1,91	
Tp	3,88	4,86	5,39	6,42	7,48	8,80	9,65	10,34	11,92	12,49	13,08	
Shape	2,90	2,22	2,31	2,75	2,02	2,15	1,93	1,93	2,40	2,00	2,16	**2,25**
Std.	0,90	0,25	0,52	0,48	0,23	0,15	0,12	0,12	0,27	0,18	0,20	**0,31**
scale	0,30	0,53	0,37	0,47	0,63	0,75	0,75	0,73	0,53	0,53	0,61	**0,56**
Std.	0,04	0,04	0,05	0,04	0,05	0,03	0,03	0,03	0,03	0,03	0,04	**0,04**

	Hs 2-3		**-75 deg**									
Rec.	1997	1095	2000	247	826	823	1092	2411	1086	2492		
Hs	2,59	2,59	2,60	2,61	2,57	2,57	2,59	2,53	2,55	2,57		
Tp	5,94	6,72	7,42	8,78	9,85	10,69	11,88	12,47	13,11	14,72		
Shape	2,08	2,18	2,29	1,91	1,74	1,90	2,01	2,13	1,91	1,97		**2,01**
Std,	0,13	0,12	0,16	0,15	0,09	0,10	0,11	0,12	0,11	0,11		**0,12**
Scale	0,76	0,92	0,79	0,62	1,23	1,33	1,06	0,92	0,85	0,83		**0,93**
Std.	0,03	0,03	0,03	0,03	0,05	0,05	0,04	0,03	0,04	0,03		**0,04**

	Hs 3-4		**-75 deg**									
Rec	403	88	862	2640	2395	367	103	2500	2498			
Hs	3,12	3,47	3,45	3,46	3,33	3,34	3,48	3,37	3,65			
Tp	6,64	7,29	8,75	9,63	10,99	11,50	12,49	13,75	14,21			
Shape	2,03	1,87	1,79	2,08	1,99	2,10	2,15	2,00	1,95			**1,99**
Std.	0,11	0,12	0,08	0,12	0,09	0,10	0,10	0,10	0,11			**0,10**
Scale	1,10	0,85	1,43	0,90	1,58	1,52	1,48	1,01	1,01			**1,21**
Std.	0,04	0,04	0,05	0,03	0,05	0,04	0,04	0,04	0,04			**0,04**

	Hs 4-5		**-75 deg**									
Rec	2615	2907	2844	100	2398	2399	2496					
Hs	4,52	4,54	4,57	4,63	4,30	4,08	4,07					
Tp	8,84	9,46	10,31	11,01	12,87	13,12	14,48					
Shape	2,0576	2,0244	2,0813	1,8335	1,9346	2,0044	2,0606					**2,00**
Std.	0,1108	0,1255	0,1086	0,1023	0,0905	0,0943	0,1062					**0,11**
Scale	1,9225	1,9467	1,171	2,0271	2,0094	1,8217	1,1397					**1,72**
Std.	0,0664	0,0816	0,0391	0,0824	0,0663	0,0569	0,0385					**0,06**

	Hs 5+		**-75 deg**									
Rec	24	98	2796	2856	2861	2858	2792	2795	2794			
Hs	5,71	5,29	5,60	6,36	6,08	7,67	8,94	8,02	9,78			
Tp	9,78	10,46	11,33	10,73	11,04	11,30	11,85	12,18	12,67			
Shape	2,13288	1,918	2,1503	1,8352	1,9499	1,885	1,9722	2,0657	2,0342			**1,99**
Std.	0,115	0,1219	0,1022	0,104	0,0919	0,0883	0,092	0,1101	0,107			**0,10**
Scale	2,095	2,7093	1,4618	1,4723	1,5039	1,7382	1,9698	1,7492	2,1027			**1,87**
Std.	0,06966	0,11999	0,0436	0,0597	0,0493	0,0578	0,0625	0,0605	0,0746			**0,07**

Figuur 6.16: Weibull parameters for impact velocities for different sea states

Chapter 7

Conclusions

Assessing the results of the workability analysis a number of things stand out. Statistics concerning the number of impacts and their velocities have been generated and analysed using a straighforward, easy to use and efficient method. The wave height extremes, which follow a Rayleigh distribution, cause impacts whose velocities follow a Weibull distribution, meaning there is a nonlinear relation between the wave height and the number and speed of collisions.

The Weibull distribution, for a particular set of parameters, constitutes a Rayleigh distribution, namely for:

$$k = 2$$

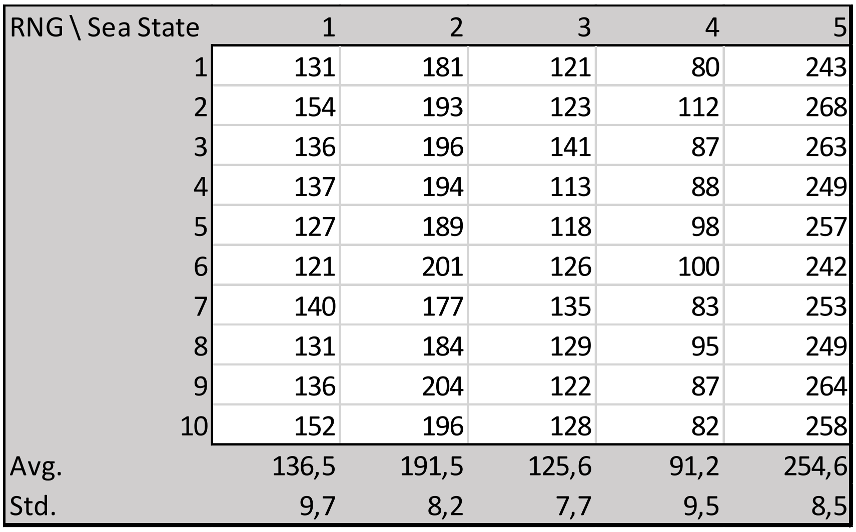
$$\lambda = \sqrt{2}\sigma$$

All the distributions of the impact velocities, however, fit this Weibull distribution remarkably well but do not conform to the Rayleigh “subset”. The shape parameter is very constant and close to 2 for pretty much all the different sea states, varying between 1,79 and 2,31, with the exception of only two sea states with very low wave heights of close to 1 m for which the shape parameter is 2,90 and 2,75. This can likely be attributed to the fact that virtually no collisions occur for these sea states, so a fit is inevitably less reliable statistically.

The scale parameter varies between 0,3 and 2,7 (see fig. 6.16). For none of the sea states for which k is approximately 2 does the condition hold for λ that would make it equivalent to a Rayleigh distribution.

Another result is that it has been demonstrated that the so-called FD-“Plus” analysis is a good method to determine the workability of offshore lifting operations as it provides a better and more precise prediction for effects unaccounted for using regular safety guidelines which typically limit operations based only on significant wave heights. It is substantially quicker than the industry standard method of doing many time domain analyses and has the added advantage that it is easily reproducable, and that the reproductability can be easily tested. The fact that the realisations are generated with specific parameters allows for a more complete assessment of the influence of ocean weather data or selected parameters on the workability.

The influence of the random number generator is verifyable as well. Creating 10 wave realisations where everything save for the RNG remains equal, we can see that the results in terms of high velocity impacts remains relatively stable with a standard deviation between 5% and 10% of the mean:



RNG \ Sea State	1	2	3	4	5
1	131	181	121	80	243
2	154	193	123	112	268
3	136	196	141	87	263
4	137	194	113	88	249
5	127	189	118	98	257
6	121	201	126	100	242
7	140	177	135	83	253
8	131	184	129	95	249
9	136	204	122	87	264
10	152	196	128	82	258
Avg.	136,5	191,5	125,6	91,2	254,6
Std.	9,7	8,2	7,7	9,5	8,5

Figure 7.3: Influence of RNG for five different sea states

The question of which variable most affects workability is less straightforward. For overall workability, the seasonal differences and their effect on overall workability are very large, meaning that work is put on hold during the more difficult months (see fig. 6.3). This effect is only reinforced by the relatively strict regulatory criteria that apply to working offshore. Most DP related criteria are expressed in terms of significant wave height only, when in fact this research shows that the influence of the wave period is very large. In fact, taking a closer look at the results for the sea states close to the regulatory limit between what is considered safe and unsafe, which is to say around Hs = 2,5, show that for certain wave periods this operation is arguably feasible. There is a factor 4 difference between the number of dangerous impacts between two different sea states that each have a significant wave height close to Hs = 2,5. That is a very big difference.

Another result is the consistency in the distributions of the impacts across various sea states. For a wave input in which the wave maxima clearly follow a Rayleigh distribution, the impacts these maxima cause all closely follow a Weibull pattern.

Chapter 8

Recommendations

It has been shown that the “FD-Plus” method provides more accurate insight into the dynamics of the lift. One area that could be of particular concern to someone doing further research into the matter is to determine whether hoisting speeds could be increased. This is the most fundamental technical variable in terms of influence on the workability of the operation.

Also, as the motion behaviour of the Aegir on the workability is significantly larger than the influence of the motion behavour of the HLOSV, more research into the damping effect of the tugger whinch system could be undertaken.

Even though a lot can be done to assess the chances of collision of the load and the deck based on OW data, the actual decision process in practise is still a very real-time decison. Advances in instuments that are able to directly measure incoming waves locally, means that for operations such as the one described in this thesis, where a critical lift takes place in just a few seconds, means that a reliable predictions of the next couple of waves means that the operation could well be feasible under more harsh environmental circumstances.

Chapter 9

Bibliography

Journée, J.M.J. and Massie, M.M.
(2000) - Offshore Hydromechanics

Holthuijsen, L.H. and Casas-Prat, M
(2010) – Short-term Statistics of Waves Observed in Deep Water

Norsok Standard
(1995) – Common Requirements Lifting Equipment

Rayleigh, Lord
(1880) – On the resultant of a large number of vibrations of the same pitch and of arbitrary phase

Longuet-Higgins, M.S.
(1952) – On the Statistical Distribution of the Heights of Sea Waves

Arena, F. and Pavone, D.
(2006) – Return Period of Nonlinear Wave Crests

Pauw, W.H., Huijsmans, R.H.M. and Voogt, A.
(2007) – Advances in the Hydrodynamics od side-by-side moored vessels

Zuo, W., Liu, M., Fan, T. and Wang, P.
(2018) – Probability Analysis of the Wave Slamming Pressure Values of the Horizontal Deck with Elastic Support

Chapter 10

Appendix

10.1 MatLab Script

```
function varargout = reellife(action, varargin)
%  reellife
%
%
%

% $TBD
% 1. proper handling of wave direction in Oceanweather data
% 2.
% $TBD-end


% the format of this file is based on these settings for the Matlab Editor:
% tab         = 8 charachters wide, tab does NOT insert spaces
% indent size = 2, classic indenting
% set this using "preferencesp ptabs"
%
% (C) 2014 JdH

% JdH template 2.20 February 2014
%
% two callings syntaxes:            PROS            CONS
%                       ====            ====
% 1. reellife('qqq')                easy            overhead
% 2. qqqFcn = reellife('fcnHandle', 'qqq')  fast, memory-efficient  need
two lines
%    feval(qqqFcn) or qqqFcn()

if ~nargin
  action    = 'readaqwa';
  action    = 'testMakeWave';
  action    = 'testMakeStats';
  %action   = 'runAQWA';

  fprintf(1,'== %s_%s ==\n', mfilename, action)

elseif isequal(action, 'fcnHandle')
  fcn           = str2func(['reellife_' varargin{1}]);
  if numel(varargin)>=2
    % 2013-03-27 added
    varargout{1}    = fcn('fcnHandle', varargin{2:end});
  else
    varargout{1}    = fcn;
```

```
  end
  return
end

if nargout
  varargout = cell(1, nargout);
  [varargout{:}]= feval(['reellife_' action], varargin{:});
else
  feval(['reellife_' action], varargin{:});
end

% _________________________________________________________
% _sub0
  function reellife_sub0

  end  % _sub0
end  % <main>

%__________________________________________________________
%% #cb
%
function reellife_cb(h, evd)

end  % #cb

%__________________________________________________________
%% #readaqwa
%
function reellife_readaqwa()

pd  = 'R:\Msc\2017-08-DinosCladesReel\data\AQWA\';
fl  = 'Step 1\analysis.lis';
flNm    = [pd fl];

aqwafile('test',flNm)

end  % #readaqwa


%__________________________________________________________
%% #makeWave   "advanced = using iFFT"
%
% advanced because
% 1. ifft more efficient than cos & sin
% 2. interpolation (refined)
% 3. directional
function tdD = reellife_makeWave(EzDir, omega, waveDir, tSpan, delta_t,
delta_omega)

tdD     = struct; % init

% interpolate in frequency scale
tdD.omegaCnt    = 1000;
tdD.waveDirCnt  = numel(waveDir);

tdD.omegaIntp   = linspace(omega(1), omega(end), tdD.omegaCnt);
delta_omegaIntp = diff(tdD.omegaIntp(1:2));
if 0
  '% @@@TEST!!! '
```

```
  tdD.omegaIntp = omega;
  delta_omegaIntp= delta_omega;
end

delta_omegaM    = delta_omega(:,ones(1, tdD.waveDirCnt));
Sz  = EzDir ./ delta_omegaM;    % [m^2 s]
% .........................................
SzIntp  = interp1(omega, Sz, tdD.omegaIntp);
% .........................................


tdD.zeta_ampl   = sqrt(2 * SzIntp .* delta_omegaIntp);  %

omega       = tdD.omegaIntp;

%.....................................................
%.....................................................
% generate random phases
tdD.phase   = rand(size(tdD.zeta_ampl)) * 2 * pi;
%tdD.phase  = tdD.phase * 0 ;   % TEST
%.....................................................
%.....................................................

if 1
  % based on iFFT
  Nfft      = ceil(diff(tSpan)/delta_t);
  if 1
    Nfft    = 2^ceil(log2(Nfft));   % nextpower
  end

  tdD.t     = ((1:Nfft)-1) * delta_t;


%..........................................................................
  %tic
  if 0
    zetaDir = ifft(...
      2 * sqrt(SzIntp *2*pi * Nfft/delta_t) .* exp(1i * tdD.phase), Nfft);
  else
    delta_omega = 2*pi/(Nfft * delta_t);
    Z_omega = tdD.zeta_ampl * delta_t * Nfft .* exp(1i * tdD.phase);
    zetaDir = ifft(Z_omega, Nfft) / delta_t;
  end

  %toc

%..........................................................................

  %.....................................................
  % sum over all directions
  tdD.zeta  = real(sum(zetaDir, 2));
  %.....................................................
  1;
else
  % based on cos()
  % time vector
  tdD.t     = tSpan(1) : delta_t : tSpan(2);
  tdD.tCnt  = numel(tdD.t);
```

```
  tdD.zeta  = tdD.t * 0;
  for oo = 1:numel(omega)
    for ww = 1:numel(waveDir)
      om        = omega(oo);
      eps_oo_ww = tdD.phase(oo, ww);

      tdD.zeta  = tdD.zeta + ...
    tdD.zeta_ampl(oo,ww) * cos(om * tdD.t + eps_oo_ww);
    end  % for ww
  end  % for oo
end

end  % #makeWave

%__________________________________________________________________________
%% #makeMotion: create time series for specified transferFcn H
%
function tdD = reellife_makeMotion(SzDir, omega, waveDir, tSpan, delta_t,
delta_omega, H, omegaH, Hs, heading)

% SzDir, omega, waveDir :
%  SzDir    directional spectral density [m@]
%   with corresponding
%       omega   radial frequencies
%      wavDir   wave directions [deg]
% delta_omega   radial frequency bandwiths
%          Hs   wav height (allows for checks and calibration)
%
% tSpan     [start finish] time [s]
% delta_t   time step [s]
%
% H     transferFcn of motion response
%   with corresponding
% omegaH    radial frequencies
%
% heading   vessel heading "in waveDir conventions"
%


tdD     = struct; % init

tdD.waveDirCnt  = numel(waveDir);

% ---- interpolate in frequency scale ----
% ERR tdD.omegaCnt  =  diff(tSpan)/delta_t; % too many points (in some way)
tdD.omegaCnt    =  1000;    % hard coded

tdD.omegaIntp   = linspace(0, omega(end), tdD.omegaCnt);
delta_omegaIntp = diff(tdD.omegaIntp(1:2));
if 0
  '% @@@TEST!!! '
  tdD.omegaIntp = omega;
  delta_omegaIntp= delta_omega;
end


% .................................................................
% interpolate (over columns of SzDir, the radial frequencies)
tdD.SzIntp  = interp1(omega,  SzDir, tdD.omegaIntp, 'linear',0);
```

```
% .................................................................

% -- calculate the proper relative wave direction --
[~,waveDirInd] = min(abs((waveDir-heading)));

if 0
  % TEST:  unidirectional, regular wave
  omega_reg = 0.7;  % [rad/s]
  [~, omegaInd] = min(abs(tdD.omegaIntp - omega_reg));

  SzIntpSave    = tdD.SzIntp;
  tdD.SzIntp(:) = 0;
  tdD.SzIntp(omegaInd, waveDirInd)  = SzIntpSave(omegaInd, waveDirInd);

end
if 0
  % TEST: remove phase lag
  H = abs(H);
end



% -- correct using energy (from Hs) --
HsFromSz    = 4 * sqrt(sum(tdD.SzIntp(:)) * delta_omegaIntp);
HsFactor    = Hs/HsFromSz;

tdD.SzIntp  = tdD.SzIntp * (HsFactor)^2;    % ;-)



% .................................................................
Hintp       = interp1(omegaH, H, tdD.omegaIntp, 'linear',0);
% @@ for some reason abs(H) does not interpolate linearly
% .................................................................

if 0
  fcns  = {@real, @imag, @abs, @angle};
  figureactivatep(900); clf
  set(gcf,'defaulttextinterpreter','tex')
  for ri = 1:numel(fcns) % @@ * doPlot('')
    % loop over plots of H
    axs(ri) = subplot(numel(fcns), 1, ri);
    % plot
    plot(omegaH, fcns{ri}(H(:, waveDirInd)),'+')
    hold on
    plot(tdD.omegaIntp, fcns{ri}(Hintp(:, waveDirInd)),'.-')

    title(sprintf('%s(H)', char(fcns{ri})))
    grid on
    legend(cprintf('%d', waveDir(waveDirInd)))
  end  % for ri
  xlabel('\omega [rad/s]')
  linkaxes(axs,'x')
end



%
%................................................................
% calculate wave elevation amplitudes fro SzDir
%        [m]    =  sqrt(   m^2 * s   1/s)
tdD.zeta_ampl   = sqrt(2 * tdD.SzIntp .* delta_omegaIntp);  %
```

```
%ERR tdD.zeta_ampl  = 0.5 * tdD.zeta_ampl;  % @@@ correction, unexplained
%................................................................

omega       = tdD.omegaIntp;

%.....................................................
%.....................................................
% generate random phases
tdD.phase   = rand(size(tdD.zeta_ampl)) * 2 * pi;
%.....................................................
%.....................................................


% based on iFFT
Nfft        = diff(tSpan)/delta_t;
Nfft        = ceil(Nfft);
%Nfft       = 2^ceil(log2(Nfft));   % see also nextpower  @@ WIP


delta_omega = 2*pi/(Nfft * delta_t);    % as check only
Z       = tdD.zeta_ampl * delta_t * Nfft .* exp(1i * tdD.phase);


%..............................................
OMEGA       = tdD.omegaIntp(ones(1,tdD.waveDirCnt), :)';
for dd = 1:size(Hintp, 3)
  % loop over DoF
  Xinterp(   :,:,dd)    = Hintp(:,:,dd) .* Z;
  XinterpDot(:,:,dd)    = Hintp(:,:,dd) .* Z * 1i .* OMEGA;
  %XinterpDot2(:,:,dd)  = Hintp(:,:,dd) .* Z .* OMEGA .* OMEGA; %DinosTest

end  % for dd
%..............................................


tdD.t       = ((1:Nfft)-1) * delta_t;
%..........................................................................
tic
zetaDir = ifft( Z      , Nfft)/delta_t;

xDir    = ifft( Xinterp,    Nfft)/delta_t;
xDirDot = ifft( XinterpDot, Nfft)/delta_t;
%xDirDot2   = ifft( XinterpDot2, Nfft)/delta_t; %DinosTest

%toc
%..........................................................................

1;

%.....................................................
% sum over all directions
tdD.zeta    = real(sum(zetaDir, 2));
tdD.x       = real(sum(   xDir, 2));
tdD.xDot    = real(sum(   xDirDot, 2));
%tdD.xDot2  = real(sum(   xDirDot2, 2));        %DinosTest
%.....................................................
```

```
tdD.zetaStd = std(tdD.zeta);

if 0
  HsCheckN  = 4 * tdD.zetaStd;
  fprintf(1,'Hs / (4 * std(zeta_t)) = %g \n', Hs/HsCheckN)
  1;
end


end  % #makeMotion


%__________________________________________________________
%% #makeTransferFcns: calculate motion transfer functions
%
function sysData = reellife_makeTransferFcns(lisData, geomData)


sysData     = struct;


freqCnt     = numel(lisData.sys.omega);
waveDirCnt  = numel(lisData.sys.waveDir);

K   = lisData.sys.K;

for oo = 1:freqCnt
  for aa = 1:waveDirCnt
    om_oo   = lisData.sys.omega(oo);
    sysData.H(:, oo, aa)    = ...
      (-om_oo^2 * (lisData.sys.M(:,:) + lisData.sys.A(:,:,oo))...
      + 1i * om_oo * lisData.sys.B(:,:,oo) ...
      + K)\lisData.sys.Hfz(:, oo, aa);
  end  % for oo
end  % for aa

% vessel 1 (MC class)
% arm from CoG to deck
[R, L] = reellife_makeRL(geomData.ves(1).deck.CoG2contact);
Ldeck       = eye(12);
Ldeck(1:3, 4:6) = -R;
Ldeck(4:end,:)  = [];

[R, L] = reellife_makeRL(geomData.ves(2).crane.CoG2tip);
Lct     = eye(12);
Lct(1:3, 4:6)   = -R;
Lct(4:end,:)    = [];

for aa = 1:waveDirCnt
  sysData.Hdeck(:,:,aa) = Ldeck * sysData.H(:,:,aa);
  sysData.Hct(  :,:,aa) = Lct   * sysData.H(:,:,aa);
end  % for aa
sysData.Hgap    = sysData.Hct - sysData.Hdeck;
1;
% build transfer function for deck motion (6 dof)


end  % #makeTransferFcns
```

```
%__________________________________________________________
%% #makeRL
%
function [R, L] = reellife_makeRL(abc)

%      | 0  b -c |
% R = |-b  0  a* |
%      | c -a  0 |
% * = Hieronder veranderd in (+)abc(1) %Dinos

R   = [
  0   abc(2) -abc(3)
  -abc(2)      0  abc(1)
  +abc(3) -abc(1)      0
  ];

L       = eye(6);
L(1:3, 4:6) = R;

end  % #makeRL


%__________________________________________________________
%% #testMakeStats
%
function reellife_testMakeStats()

inD = struct;
inD.t.tic   = tic;
inD.t.start = now;

% ---
pd  = reellife('folder','aqwa');
fl  = 'step3i_shiftS1toCoG.lis';

inD.lisFlNm = [pd fl];

% ---
%  == file ==
pd  = reellife('folder','OW');
fl  = '2012_30Km_GP00GPGP_Spec.mat';
inD.owFlNm  = [pd fl];


% ---
inD.heading = -75;      % [deg]
%inD.heading    = [-90 -45 0];  %TestDinos

% ---
inD.HchoiceNm   = 'z2'; % heave vessel 2
inD.HchoiceNm   = 'z1'; % heave vessel 1
inD.HchoiceNm   = 'delta_z_gap';

% ---
% define time span (FFT setup can overrule this)
inD.tSpan   = [0 3600]; %Save
```

```
%inD.tSpan  = [0 36000];

inD.tSpan(2)    = inD.tSpan(2) * 10;    % TEST: very long time span
%inD.tSpan  = [0 100000];   % QUICK TEST

% -
inD.delta_t     = 0.1;      % [s]   % time step

% ----
geomData    = struct;
geomData.ves(2).name        = 'Aegir';
geomData.ves(1).name        = 'MC-class';

geomData.ves(2).crane.CoG2tip   = [-30 -48 40];

geomData.ves(1).deck.CoG2contact= [  0   0  5];     %Save
%geomData.ves(1).deck.CoG2contact= [  0   0  15];    %TestDinos

inD.geomData    = geomData;

% ----
% -- post process --
% parameters to use in statistical post-processing
statsPar.gaps       = [0.1 0.5 1];      % [m]   CRUDE
statsPar.gaps       =  0.2:0.01:1.6;    % [m]   refined <<<<<<<<<<< use
this
statsPar.gaps       =  0.2:0.05:1.6;    % [m]    courser
statsPar.gaps      =  0:0.2:3.5      % Dinos
%statsPar.gaps  =  0.3:0.05:1.4;    % [m]   % TEST, fast

statsPar.impactThreshold    = 0.2;      % [m/s]
%statsPar.impactThreshold   = 3;        %Dinos


inD.statsPar    = statsPar;

inD.dateInds(1)     = 1997;
inD.dateInds(2)     = 1095;
inD.dateInds(3)     = 2000;
inD.dateInds(4)     = 247;
inD.dateInds(5)     = 826;
inD.dateInds(6)     = 823;
inD.dateInds(7)     = 1092;
inD.dateInds(8)     = 2411;
inD.dateInds(9)     = 1086;
inD.dateInds(10)    = 2492;


% ............................................
% ............................................
[statsD, outD, sysData, waves, rngState] = ...
  reellife_makeStats(inD);
% ............................................
% ............................................

varNms  = { % the selection of data to save
  'inD'
  'statsD'
  'outD'
```

```
  'sysData'
  'waves'
  'rngState'
  };

dv  = datevec(inD.t.start);
fl  = sprintf('RL%4d-%02d-%02d_%02d%02d%02d_%s[%d %d].mat',...
  round(dv), inD.HchoiceNm, inD.tSpan);
save(fl, varNms{:})

reellife_plotStats(inD, outD, statsD, waves, rngState)

end  % #testMakeStats


%__________________________________________________________
%% #makeStats
%
function [statsD, outD, sysData, waves, rngState] = ...
  reellife_makeStats(inD)

outD        = struct;

% % do a test on a single record
% dateStrChoice = '1-Jan-2012 0:00';


% --- input parameters ---
heading     = inD.heading;      % [deg]
HchoiceNm   = inD.HchoiceNm;    %
geomData    = inD.geomData;
%

% time span (FFT setup can overrule this) & time step
tSpan       = inD.tSpan;
delta_t     = inD.delta_t;      % [s]   % time step


% --- load hydrodynamic coefficients ---
global lisDataG
if isempty(lisDataG)
  % cache empty, so read from disk
  [lisData,  msgC] = AQWAfile('readLIS', inD.lisFlNm);
  % == store data in global (persistent) memory ==
  [lisDataG, msgC] = AQWAfile('processLIS', lisData);
end
lisData = lisDataG;

%..........................................
sysData = reellife_makeTransferFcns(lisData, geomData);
%..........................................

if 0
  fig3D = figureactivatep(301); clf
  [fig, ax] = AQWAfile('testDraw',lisData, fig3D);

  % vessel 1
  xyzDeck       = lisData.inertia(1).xyzCoG + ...
```

```
    geomData.ves(1).deck.CoG2contact;

  xyzCraneTip   = lisData.inertia(2).xyzCoG + ...
    geomData.ves(2).crane.CoG2tip;


  lnPrp     = struct;
  lnPrp.Parent  = ax;
  lnPrp.Marker  = '*';

  lnPrp.XData   = xyzDeck(1);
  lnPrp.YData   = xyzDeck(2);
  lnPrp.ZData   = xyzDeck(3);
  lnPrp.Color   = 'g';
  line(lnPrp)

  lnPrp.XData   = xyzCraneTip(1);
  lnPrp.YData   = xyzCraneTip(2);
  lnPrp.ZData   = xyzCraneTip(3);
  lnPrp.Color   = 'g';
  line(lnPrp)
  drawnow
end


% === load OceanWeather Hindcast wave data ===

% == store data in memory ==
global owDataG
if isempty(owDataG)
  % cache empty, so load from disk
  owDataG= load(inD.owFlNm);
end
owData  = owDataG;

% == put wave date in waves structure ==
% the variance = wave enregy per freq, per directions
waves.dateser   = owData.dateser;
waves.omega = owData.header.frequencies * 2*pi; % [rad/s <-- Hz]
waves.omegaUnits = 'rad/s';

waves.waveDir   = owData.header.sectors;

%.......................................................
% sort by freq, waveDir, record (3hrs interval record "slow",long time
scale)
waves.EzDir = permute(owData.varianceComps,[2 3 1]);%
%.......................................................
waves.EzDirUnits= 'm^2';    % NOTE not an energy density

% NOTE frequency vector not uniformly spaced!
waves.delta_omega = owData.frequencyBandwidth * 2 * pi;   % [rad/s]

waves.Hs    = owData.HS;

% -- do a check on data, calculate Hs from Ez --
waves.m0    = sum(waves.EzDir, 1);
waves.m0    = sum(waves.m0   , 2);
waves.m0    = squeeze(waves.m0);
```

```
waves.HsCheck   = 4 * sqrt(waves.m0);   % for all records

if 1
  figureactivatep(101); clf
  axs(1)    = subplot(4, 1, 1:3);
  plot(waves.dateser, waves.Hs);
  hold all
  plot(waves.dateser, waves.HsCheck);
  legend('Hs','HsCheck')
  grid on
  datetick

  axs(2)    = subplot(4, 1, 4);
  plot(waves.dateser, waves.Hs - waves.HsCheck);
  grid on

  linkaxes(axs,'x')
  drawnow
end


copyvarp  % TEST

% *************************************************************************
% * wave direction conventions
% *
% * AQWA: incoming waves to stern = 0 deg, counter-clockwise (mathematical
convention)
% *
% *   OW: "waves from North" = 0 deg, clockwise (nautical convention)
% *
% * relation
% *
% * wd_aqwa = 180 - wd_OW + heading
% *

% ---- handle wave directions ----
sysDataOrg  = sysData;
lisWaveDir  = lisData.sys.waveDir;
lisWaveDir(1)   = [];

% bring the wave directions of the wave spectra in line with aqwa
conventions
waveDirWaves    = 180 - waves.waveDir + heading;    % OW = OceanWeather
waveDirVessel   = lisData.sys.waveDir;          % AQWA

% remove 180 (we have -180 already)
keepIndL        = waveDirVessel~=180;
waveDirVessel(~keepIndL)= [];

% wrap to [-180  180)
indL        = waveDirWaves<-180;
waveDirWaves(indL)=waveDirWaves(indL) + 360;
indL        = waveDirWaves> 180;
waveDirWaves(indL)=waveDirWaves(indL) - 360;

[~, waveSortInd]= sort(waveDirWaves);

% extend to allow for interpolation
```

```
waveSortInd = waveSortInd([end 1:end 1]);

waveDirWaves    = waveDirWaves(waveSortInd);
waveDirWaves( 1 ) = waveDirWaves( 1 ) - 360;
waveDirWaves(end) = waveDirWaves(end) + 360;

% ========================================
if 1
  switch class(inD.dateInds)
    case 'char'
       % @@@ 'all'
      dateInds  = 1:numel(waves.dateser);
    otherwise
      % take literal
      dateInds  = inD.dateInds;
  end

elseif 1
  % -- multiple --
  %dateInds = 1:2;      % TEST  , first two date racords
  dateInds  = 1:numel(waves.dateser);
  %dateInds = ones(1, 10);  % TEST, repeat a record many times to see
dependence on random phase
else
  % -- take closest date record --
  dateserCh = datenum(dateStrChoice);
  [~,dateInds]  = min(abs(waves.dateser - dateserCh));
end
outD.dateInds   = dateInds;  % save


if 0
  % @@ make this an input par

  % reset random number generator
  rng('default');

else
  '@@@@@@@@ use input for RNG seed'
  % use current date/time as seed
  di    = uint32(now * 1e3);
  rng(di);
end


ddi = 0;    % increment
for dd = dateInds
  ddi   = ddi + 1;
  fprintf(1, 'Run %3d record %3d ... ', ddi, dd)

  % EzDir: directional wave variance with directions according to OW
convention
  EzDir = waves.EzDir(:, :, dd);

  % since EzDir is not a density we should not interpolate
  delta_omegaM  = waves.delta_omega(:, ones(1, size(EzDir,2)));

  SzDir = EzDir ./delta_omegaM;
```

```
  % wave directions according to AQWA convention
  SzDir = SzDir(:, waveSortInd);

  % SzDir interpolated to AQWA wave directions
  SzDir = interp1(waveDirWaves, SzDir', waveDirVessel)';

  % we might have introduced an error, correct for it later
  %  using Hs
  1;

  if 1
    fig = figureactivatep(102); clf
    menudebug('build', fig);
    axPrp       = struct;
    axPrp.Parent    = fig;
    axPrp.Visible   = 'on';
    %axPrp.XLim

    ax  = axes(axPrp);

    surfPrp     = struct;
    surfPrp.Parent  = ax;
    surfPrp.XData       = waves.omega;
    surfPrp.YData       = waves.waveDir;
    %%surfPrp.ZData = log10(EzDir)';
    surfPrp.ZData       = SzDir';
    surfPrp.CData       = SzDir';
    surfPrp.FaceColor   = 'interp';
    surfPrp.EdgeColor   = 'w';
    surfPrp.EdgeAlpha   = 0.1;
    surface(surfPrp)

    %surf(waves.omega, waves.waveDir, EzDir')
    title(sprintf('SzDir [m^2 s] %s, Hs = %g',...
      datestr(waves.dateser(dd),0), waves.Hs(dd)))
    view([0 90])
  end

  % ========================================
  % create a wave realisation by adding random phase information to each
component
  %  one energy component per frequency and wave direction
  rngState(ddi) = rng;  % save the state of the random generator


  % choose H
  %    switch HchoiceNm
  %      case 'delta_z_gap'
  %        H        = sysData.Hgap(3,:,keepIndL);
  %      case 'z1'
  %        H        = sysData.H(   3,:,keepIndL);
  %      case 'z2'
  %        H        = sysData.H(   9,:,keepIndL);
  %      otherwise
  %        error('.')
  %    end

  % choose H --TestDinos
  switch HchoiceNm
```

```
    case 'delta_z_gap'
      H     = sysData.Hgap(3,:,keepIndL);
    case 'z1'
      H     = sysData.H(   3,:,keepIndL);
    case 'z2'
      H     = sysData.H(   9,:,keepIndL);
    otherwise
      error('.')
  end

  % put DoF in third dimension
  H     = permute(H, [ 2 3 1]);


  fprintf(1, 'motions ... ');
  % .......................................................................
  tdD       = reellife_makeMotion(      SzDir, waves.omega,
waveDirVessel,...
    tSpan, delta_t, waves.delta_omega, H, lisData.sys.omega, owData.HS(dd),
heading);
  % .......................................................................


  % -- check  --
  m0        = sum(EzDir(:));

  Hs1Check(1)   = owData.HS(dd);
  Hs1Check(2)   = 4 * sqrt(m0);
  Hs1Check(3)   = 4 * std(tdD.zeta);

  %Hs1Check % for a single record

  respCheck(3)  = 4 * std(tdD.x);


  %min(tdD.zeta)    % wave amplitudes per freq

  if 1

    figureactivatep(112); clf
    set(gcf,'defaulttextinterpreter','tex')


    subplot(3,5,1:5)
    plot(waves.omega, sum(SzDir,2),'+');
    grid on
    hold all
    plot(tdD.omegaIntp, sum(tdD.SzIntp,2));

    xlabel('\omega [rad/s]')
    legend('Sz [m^2 s]')
    title(sprintf('Hs = %g m, %s',...
      waves.Hs(dd),...
      datestr(waves.dateser(dd),0)))

    axs(2)  = subplot(3, 5, 6:8);
    plot(tdD.t, tdD.zeta,'.-');
    xlabel('t [s]')
```

```
    ylim([-1 1] * owData.HS(dd))
    grid on
    title('\zeta')

    axs(3)  = subplot(3, 5 , 11:13);
    plot(tdD.t, tdD.x,'.-');
    xlabel('t [s]')
    %ylim([-1 1] * owData.HS(dd))
    grid on
    title(HchoiceNm,'interpreter','none')

    % scatter plot
    subplot(3,5, [9 10 14 15])
    plot(tdD.zeta, tdD.x, '.')
    axis equal
    %axis log %TestDinos
    grid on

    linkaxes(axs(2:3),'x')

  end
  drawnow
  copyvarp  % TEST



  fprintf(1, 'stats ... ');
  %.............................................
  statsD_dd = reellife_postStats(tdD, inD.statsPar);
  %.............................................

  % ................................
  statsD(:, ddi)    = statsD_dd;
  % ................................

  elapsed   = toc(inD.t.tic);
  progress  = ddi/numel(dateInds);
  total     = elapsed/progress;
  left      = (1-progress) * total;

  fprintf(1, 'done. (ready in %d minutes)\n', ceil(left/60));
end  % for dd

end  % #makeStats

%___________________________________________________________
%% #plotStats
%
function reellife_plotStats(inD, outD, statsD, waves, rngState)

statsPar    = inD.statsPar;

txtPrp  = struct;
txtPrp.Units    = 'norm';
txtPrp.Position = [0.98 0.98];
txtPrp.HorizontalAlignment  = 'right';
txtPrp.VerticalAlignment    = 'top';
```

```
ddi = 0;
for dd = outD.dateInds
  ddi   = ddi + 1;
  statsD_dd = statsD(:, ddi);

  % ----
  %figure(799), clf  %SaveDinos
  figure(700 + ddi)

  axs(1)    = subplot(5, 1, 1:4);
  impactCnts        = [];
  for gg = 1:numel(statsD_dd)

    impactCnts_gg   = numel(statsD_dd(gg).impactVel);
    x   = statsD_dd(gg).gap * ones(1,impactCnts_gg);
    y   =-statsD_dd(gg).impactVel';

    %............
    plot(x,y,'s')
    %............

    hold all

  end  % for gg
  xlim([min(statsPar.gaps) max(statsPar.gaps)])
  %ylim([0 1.3])
  ylim([0 3])     %Dinos
  %ylim([min(statsPar.impactVel) max(statsPar.impactVel)]) %DinosTest
  grid on

  title('Impact velocity vs. gap size')
  ylabel('[m/s]')
  set(axs(1),'xticklabel',{})

  txtPrp.String = sprintf('%d: %s, Hs = %g, RNG state = %d', ddi, ...
    datestr(waves.dateser(dd),0), waves.Hs(dd), sum(rngState(ddi).State));
  text(txtPrp)

  % --
  axs(2)    = subplot(5, 1, 5);
  x = [statsD_dd(:).gap];
  y = [statsD_dd.sigImpactCnts];
  plot(x,y,'.-')
  xlabel('gap size [m]')
  ylabel('[-]')
  grid on

  %txtPrp.String    = sprintf('Nr of significant impacts (impact vel > %g
[m/s])', statsPar.impactThreshold);
  %text(txtPrp)

  linkaxes(axs(1:2),'x')
  pause(0.1)
end  % for dd


end  % #plotStats
```

```
%__________________________________________________________
%% #testMakeWave
%
function reellife_testMakeWave()


% === load OceanWeather Hindcast wave data ===

%  == file ==
pd  = reellife('folder','OW');
fl  = '2012_30Km_GP00GPGP_Spec.mat';
owFlNm  = [pd fl];

% use cache memory to speed up
global owDataG
if isempty(owDataG)
  % == store data in memory ==
  % cache empty, so load from disk
  owDataG= load(owFlNm);
end
owData  = owDataG;

% == put wave date in waves structure ==
% the variance = wave enregy per freq, per directions
waves.dateser   = owData.dateser;
waves.omega = owData.header.frequencies * 2*pi; % [rad/s <-- Hz]
waves.omegaUnits = 'rad/s';
waves.waveDir   = owData.header.sectors;
% do some processing on wave directions
[~,ind]         = min(waves.waveDir);
ind         = 1:ind-1;
waves.waveDir(ind)  = waves.waveDir(ind)-360;

%.......................................................
% sort by freq, waveDir, record ("slow" time scale)
waves.EzDir = permute(owData.varianceComps,[2 3 1]);%
%.......................................................
waves.EzDirUnits= 'm^2';    % NOTE not an enrgy density

% NOTE frequency vector not uniformly spaced!
waves.delta_omega = owData.frequencyBandwidth * 2 * pi;   % [rad/s]

waves.Hs    = owData.HS;

% -- do a check on data, calculate Hs from Ez --
waves.m0    = sum(waves.EzDir, 1);
waves.m0    = sum(waves.m0   , 2);
waves.m0    = squeeze(waves.m0);
waves.HsCheck   = 4 * sqrt(waves.m0);   % for all records

if 1
  figureactivatep(101), clf
  axs(1)    = subplot(4, 1, 1:3);
  plot(waves.dateser, waves.Hs);
  hold all
  plot(waves.dateser, waves.HsCheck);
  legend('Hs','HsCheck')
  grid on
```

```
  datetick

  axs(2)    = subplot(4, 1, 4);
  plot(waves.dateser, waves.Hs - waves.HsCheck);
  grid on

  linkaxes(axs,'x')
end


copyvarp  % TEST

% ========================================

% -- do a test on a single record --
dateInd = 1500;
EzDir   = waves.EzDir(:,:, dateInd);

% -- check  --
Hs1Check(1) = owData.HS(dateInd);
Hs1Check(2) = 4 * sqrt(sum(EzDir(:)));

if 1
  fig   = figureactivatep(102); clf
  menudebug('build', fig);
  axPrp     = struct;
  axPrp.Parent  = fig;
  axPrp.Visible = 'on';
  %axPrp.XLim

  ax    = axes(axPrp);

  surfPrp       = struct;
  surfPrp.Parent    = ax;
  surfPrp.XData = waves.omega
  surfPrp.YData = waves.waveDir;
  %%surfPrp.ZData   = log10(EzDir)';
  surfPrp.ZData = EzDir';
  surfPrp.CData = EzDir';
  surfPrp.FaceColor = 'interp';
  surfPrp.EdgeColor = 'w';
  surfPrp.EdgeAlpha = 0.1;
  surface(surfPrp)

  %surf(waves.omega, waves.waveDir, EzDir')
  title(sprintf('EzDir [m^2] %s, Hs = %g',...
    datestr(waves.dateser(dateInd),0), waves.Hs(dateInd)))
  view([0 90])
end

% ========================================
% create a wave realisation by adding random phase information to each
component
%  one energy component per frequency and wave direction


if 0
  rng('default');   % reset random number generator
end
```

```
% define time span (FFT setup can overrule this)
tSpan   = [0 3600]; %SaveDinos
%tSpan  = [0 36000];

delta_t     = 0.1;      % [s]   % time step
if 1
  % ..................................................................
  tdD       = reellife_makeWave(      EzDir, waves.omega, waves.waveDir,...
    tSpan, delta_t, waves.delta_omega);
  % ..................................................................
else
  tdD       = reellife_makeWaveSimple(EzDir, waves.omega, waves.waveDir,
tSpan, delta_t);
end


Hs1Check(3) = 4 * std(tdD.zeta);   % Journee 5.3.4.2

Hs1Check    % for a single record

min(tdD.zeta)   % wave amplitudes per freq

if 1

  figureactivatep(111), clf


  subplot(2,1,1)
  plot(waves.omega, abs(sum(EzDir,2)),'+');
  grid on
  hold all
  %plot(omegaIntp, abs(ZnoDir));
  legend('EzDir [m^2]')

  subplot(2,1,2)
  plot(tdD.t, tdD.zeta);
  xlabel('t [s]')
  ylim([-1 1] * owData.HS(dateInd))
  grid on
end

drawnow
copyvarp  % TEST


end  % #testMakeWave

%__________________________________________________________
%% #postStats
%
function statsD = reellife_postStats(tdD, statsPar)


statsD  = struct;


for gg = 1:numel(statsPar.gaps)
```

```
  % ---- find impacts ----
  % relative height,  reverse sign
  x_t   = -(tdD.x + statsPar.gaps(gg));

  x_t(x_t<0) = 0;


  %cla, plot(x_t,'.-'), return

  [pks, ind]    = findpeaks(x_t);
  drawnow  % to be able to interrupt

  % find the last point before the signal gets negative
  zcInd = findzerocross(tdD.x + statsPar.gaps(gg), '+-');

  % interpolation to find out what the exact +- zerocrossing is
  alpha = (tdD.x(zcInd)+ statsPar.gaps(gg))./(tdD.x(zcInd) -
tdD.x(zcInd+1));


  %pks  = -(statsPar.gaps(gg) + pks);
  pks   = -pks;

  statsD(gg).gap    = statsPar.gaps(gg);
  statsD(gg).pks    = pks;
  statsD(gg).pksInd = ind;
  statsD(gg).zcInd  = zcInd;
  statsD(gg).alpha  = alpha;
  statsD(gg).impactVel  = tdD.xDot(zcInd);  % @@@ use alpha

  % significant impacts (above threshold)
  statsD(gg).sigImpactCnts  = sum(-statsD(gg).impactVel >
statsPar.impactThreshold);

end  %for gg

% ---------------------------------------------------------------------------
figPrp  = struct;

for gg = 1:numel(statsPar.gaps)*0
  % ---- plot impacts ----
  pks       = statsD(gg).pks;
  ind       = statsD(gg).pksInd;
  zcInd     = statsD(gg).zcInd;
  alpha     = statsD(gg).alpha;

  % --
  fig   = 700+gg;
  figureactivatep(fig), clf
  figPrp.Name   = sprintf('impacts for gap%02d = %g m', gg,
statsPar.gaps(gg));
  set(fig, figPrp)

  axs(3)    = subplot(4, 1, 4);
  plot(tdD.zeta,'.-')
  title('surface elevation \zeta [m]')
  grid on
```

```
  axs(2)    = subplot(4, 1, 3);
  plot(tdD.xDot,'.-')
  title('velocity [m/s]')
  hold all
  grid on

  axs(1)    = subplot(4, 1, 1:2);


  plot(tdD.x + statsPar.gaps(gg),'.-')
  hold all
  grid on

  axes(axs(1))      % plot: (relative) position response
  plot([1 numel(tdD.x)], -[1 1] * statsPar.gaps(gg))
  plot(ind, pks,'o')
  plot(zcInd, zcInd*0,'s')



  axes(axs(2))      % plot: velocity
  plot(ind, tdD.xDot(ind),'v')

  plot(zcInd, tdD.xDot(zcInd),'^')

  linkaxes(axs,'x')
  1;
end  % for gg

end  % #postStats

%__________________________________________________________
%% #folder
%
function pd = reellife_folder(type)

pcNm    = computername;
atTU    = strncmpi('tud', pcNm, 3);
if atTU
  root  = 'R:\MSc\2017-08-DinosCladesReel\';    % ending sep!!!
else
  % Dinos
  root  = 'C:\Reellift\';
end


switch type
  case 'data'
    pd  = [root type filesep];
  case 'OW'
    pd  = [root 'data' filesep 'OW' filesep];
  case 'aqwa'
    pd  = [root 'data' filesep 'AQWA' filesep 'Step3i' filesep];
  otherwise
    error('.')
end

check   = true;
```

```
if check && ~exist(pd,'dir')
  error('.')
end

if nargout
  return
end
% open folder in Windowds explorer
winopen(pd)

end  % #folder

%__________________________________________________________
%% #runAQWA
%
function reellife_runAQWA(runNm)

if nargin<1
  runNm     = '';
end

tmpPd   = 'C:\Users\joosthaan\AppData\Local\Temp\AQWA_runs\';
switch runNm
  case {'FDsafe'}
    datPd   = '2018-01-29_16-04-07_Ansys_18.1-safe';
    datFl   = 'step3i_shiftS1toCoG.dat';
  case {'FDwd10'}
    datPd   = '2018-01-29_16-04-07_Ansys_18.1-wd10';
    datFl   = 'step3i_shiftS1toCoG.dat';
  case {'','TDtest1'}
    datPd   = '2018-01-29_16-04-07_Ansys_18.1-work';
    datFl   = 'step3i_shiftS1toCoG.dat';
  otherwise
    error('.')
end


fprintf(1,'\nRunning AQWA with "%s"\n  from "%s"\n', datFl, datPd)
datFlNm     = [tmpPd datPd filesep datFl];

AQWAfile('run','start', datFlNm, 18.1,'-noWait')    % ,'-foreground'
end  % #runAQWA

%__________________________________________________________
%% #qqq
%
function reellife_qqq()

end  % #qqq

%__________________________________________________________
%% #rrr
%
function varargout = reellife_rrr(action, varargin)

%optionsIndL        = strncmpi('-', varargin, 1);
%options        = varargin(optionsIndL);
%varargin(optionsIndL)  = [];
%
```

```
%option         = any(strcmpi('-option',options));

varargout       = cell(1, nargout);

switch action
  case 'fcnHandle'
    [varargout{:}]  = eval(['@reellife_rrr_', varargin{1}]);
    return
  case 'sss'
    % _rrr_sss
    varargout{1}    = reellife_rrr_sss(varargin{:});
    % _rrr_sss END
  otherwise
    error('.')
end

% _________________________________________________________
% _rrr_sub1
  function reellife_rrr_sub1

  end  % _rrr_sub1

end  % #rrr
```